HANDBOOK

FOR

HIGHWAY ENGINEERS

CONTAINING INFORMATION ORDINARILY USED
IN THE DESIGN AND CONSTRUCTION
OF RURAL HIGHWAYS

art I. Principles of General Planning & Design
art II. Field & Office Detail Data
art III. Specifications
art IV. General Tables & Formulae
ppendix. First Aid (Accidents)

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FOURTH EDITION
ENTIRELY REVISED AND ENLARGED
SECOND IMPRESSION

McGRAW-HILL BOOK COMPANY, INC.
NEW YORK: 370 SEVENTH AVENUE
LONDON: 6 & 8 BOUVERIE ST.; E. C. 4
1927

PRINTED IN THE UNITED STATES OF AMERICA

THE MAPLE PRESS COMPANY, YORK, PA.

PREFACE TO FOURTH EDITION

This edition contains the selected data which 14 years use of the older editions indicates as desirable to meet the requirements of the everyday work of Highway Engineers. It includes information ordinarily needed for General Planning and for the detail work of Surveys, Design and Construction.

A Revision is necessary at this time on account of the rapid strides made in Rural Road Practice to meet the increased demands of modern motor traffic. The text has been entirely rewritten. Construction and Reconstruction methods and costs have been brought up to date; General Economics and Railroad Grade Crossing protection data have been added at the request of users and a number of additional convenient design tables have been introduced. The additions total 700 pages.

The discussion of general principles of economics and design illustrated by examples of Current Practice in Part I has been made more thorough as it is our experience that if the younger men have a good understanding of broad general principles they can more readily apply the detail rules to specific problems.

The general character of the second part of the book remains unchanged; namely a concise collection of data ordinarily required for everyday work.

For the convenience of users the book is bound either complete in one volume for office men or students or in two volumes for field men which gives a handy pocket thickness for the volume containing the field data. A full table of contents as well as the regulation index adds to the ease of locating desired information.

Readers are requested to suggest additions or changes in style of presentation which will increase the value of the book. The present edition is the outgrowth of such suggestions.

E. A. Bonney has supplied the data on Contractors Equipment. W. G. Harger has handled the balance of the revision.

W. G. Harger.
E. A. Bonney.

Rochester, N. Y., September, 1927.

PREFACE TO THIRD EDITION

The present revision was undertaken in response to the suggestions and requests of many users of the earlier editions. The practical value of the Handbook is increased by the addition of approximately 350 pages of new material covering mountain road location and design, camp equipment, medical notes, notes on photography, the selected soil and gravel treatment of moderate traffic roads, and the more recent developments of hard surfaced types. There is no change in the general scheme of the publication, which is primarily a compact collection of reference data and time saving tables. For the benefit of men not entirely familiar with the road problem, the discussion of principles has been retained, and in some cases where it has been shown that certain arguments in the previous editions have failed to make the impression warranted by their importance, the discussion has been amplified and illustrated by examples of construction and design. We wish particularly to emphasize gradeline design, which is not at present receiving the attention to which it is entitled, and also point out the practically universal lack of adequate maintenance.

The costs given in the body of the text are for comparative purposes only and are based on labor at from $0.175 to $0.20 per hour and material costs of the period 1912 to 1915.

For the improvement of future editions we request your coöperation in the correction of typographical errors, and the addition of any omitted data generally useful in road work.

Very few highway engineers are satisfied with the road legislation or technical practice of today or believe that it can be applied as it stands to solve the highway problem in this country in the next fifty years, but the data that has been collected from experience serves as a basis for future improvement. There is every reason to be optimistic in regard to road development provided the problem is approached with constructive imagination and encouragement is given to departure from methods whose main defense lies in precedent or habit.

The work of revision for this edition is entirely that of W. G. Harger.

W. G. H.
E. A. B.

Rochester, N. Y., January, 1919.

PREFACE TO SECOND EDITION

SINCE the publication of the first edition of this book four years ago, considerable progress has been made in the practice of road design and construction. To meet this advance, thi handbook has been revised by bringing the material on top courses up-to-date, and by adding considerable data on tests, designs, costs, maintenance and specifications. Not only has much of the old material been revised, but new material, totaling approximately 100 pages, has been added. The criticisms and suggestions of many who have used the book in the field and office have aided the authors in this revision.

A more complete and systematic index has been prepared by Mr. Percy Waller.

The general arrangement of the book remains untouched.

W. G. H.
E. A. B.

ROCHESTER, N. Y., May, 1916.

PREFACE TO FIRST EDITION

THE purpose of this book is to collect, in a compact and convenient form, information ordinarily required in the field and office practice of road design and construction.

The book is designed to meet the requirements of both experienced and inexperienced road men. The material on the relative importance of the different parts of the design, and the possibilities of economy, without impairing the efficiency of the road, are primarily for the inexperienced engineer. The collection of cost data and the tables will be useful to any one engaged in road work.

As it is difficult to avoid clerical errors and mistakes in proofreading in first editions, we shall appreciate the coöperation of readers in calling our attention to any errors.

W. G. H.
E. A. B.

ROCHESTER, N. Y., April, 1912.

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HANDBOOK
FOR
HIGHWAY ENGINEERS

PART I—PRINCIPLES AND PRACTICE

CHAPTER I

GENERAL ADMINISTRATIVE, ENGINEERING, AND ECONOMIC DATA

Introduction.—There is no object in giving an extended discussion of the general highway problem in a handbook of this character. The reader is referred to the many excellent highway books and official government publications for such a discussion. This chapter summarizes briefly the main points to be considered and tabulates basic administrative and economic data.

Public business as well as private business is usually based on the fundamental idea of creating a demand for commodities or services in order that large sums of money may be collected and its expenditure controlled by the constituted authorities. In order to produce a healthy and long-lived business, public or otherwise, it is necessary to follow a line of procedure which is both popular and economically defensible and which raises the living standards of the community and increases its productive capacity. The highway executive must decide what will be popular and at the same time good business. He must distribute rewards for large public expenditures on a reasonable basis between the capitalistic or banker class, by some use of bonds and other interest-bearing methods, and the laboring and active business interests, by utilizing most of his expenditures for human labor and the development of actively productive business enterprises of road material and equipment manufacture.

In the pursuit of the universal and laudable object of public works, highway executives are between two fires: the desire of constituents for perfection in travel comfort, and a reasonable type of road improvement, taking into consideration the economics of highway service and cost. General policy must usually be a compromise between business utility standards and the natural desire of all individuals and communities to get as much pleasure out of existence as they can regardless of cost or regardless of the business wisdom of expenditure for luxuries. The main value of highway economics lies in providing a basis for judgment considering the problem from a business standpoint. *The practical use of economics*

is largely confined to providing a check on extravagance, as the desire of communities for excellent roads has much more influence on general administrative policy than the economic point of view.

Successful general policy must be flexible in order to cover the wide range of traffic requirements from cheap earth development roads in pioneer districts to the heavy-traffic boulevards of metropolitan districts, and requires careful consideration of the relative cost and value of the different stages of highway improvement. Complete highway programs include three well-defined branches coordinated by centralized administration:

1. The immediate temporary improvement of portions of the system not yet reached by the modern construction program.

2. The gradual improvement of the road system by means of economic locations, modern pavements and bridges suitable for the traffic each road must carry, and the proper care of detours during construction.

3. The maintenance and renewal of such high-grade improvements.

FIG. 1.—North Carolina progressive improvement.

As available funds are rarely sufficient to meet the final desires or needs of the community, it has been found that the policy of "progressive improvement" is a good practical solution, as each stage of improvement materially increases the comfort and safety of traffic and reduces its cost as compared with previous conditions, which retains the continued support of taxpayers for the gradually increasing costs during the period of years necessary for the completion of a satisfactory and economically defensible system of roads. Progressive improvement recognizes the two main stages of highway construction listed in the preceding paragraph: It

emphasizes the well-established principle that the first necessity is the rapid construction of a complete system of moderate-priced roads which will give the community year-round service for its ordinary business needs, and that after this is accomplished it is desirable to raise gradually the standards of comfort and convenience to the highest point which the community can afford.

Reasonable administrative policy and engineering design give careful consideration to the following factors, which are discussed briefly:

1. General Value and Cost of Highway Improvements.—Highway value consists of two factors, first the indirect general benefits expressed in terms of higher standards of living, greater power of communication, and better general values as listed in Table 1, and, second, the direct reduction in cost of vehicle operation.

In order to insure a real profit on investment, highway expenditures should have some reasonable relation to the value of the proposed improvements, and analyses of the indirect and direct values of highways are well worth while in arriving at general limits of expenditure. In some cases these analyses indicate that increased expenditures are desirable, and in some cases that proposed expenditures exceed rational amounts. As a general rule, permissible increases apply only to main roads, carrying over 1500 vehicles daily, and reductions to moderate-traffic roads carrying less than 1000 daily. For roads carrying less than 300 to 500 vehicles daily, the general intangible benefit usually controls both minimum and maximum expenditures. For roads carrying more than 500 to 1000 vehicles daily, the direct reduction in travel cost controls permissible maximum expenditures, which in most cases permit economic design; on these roads general intangible benefit fixes the extreme minimum of expenditures (see Fig. 3, p. 16). There is no doubt that rational highway expenditures are a sound business investment for all communities, but in many cases the general public has been gradually educated up to high-type roads and extreme comfort of travel without any real understanding of the economics of the matter, and the present insistent demands for excessive expenditure on moderate-traffic roads are somewhat disturbing. It is believed that it is desirable to set reasonable

economic limits for such cases. While needless expenditures are not economically defensible, it is quite obvious that highways cannot be considered solely from an economic standpoint and that analyses of this nature are only one phase of the problem.

TABLE 1.—INDIRECT VALUE OF HIGHWAYS

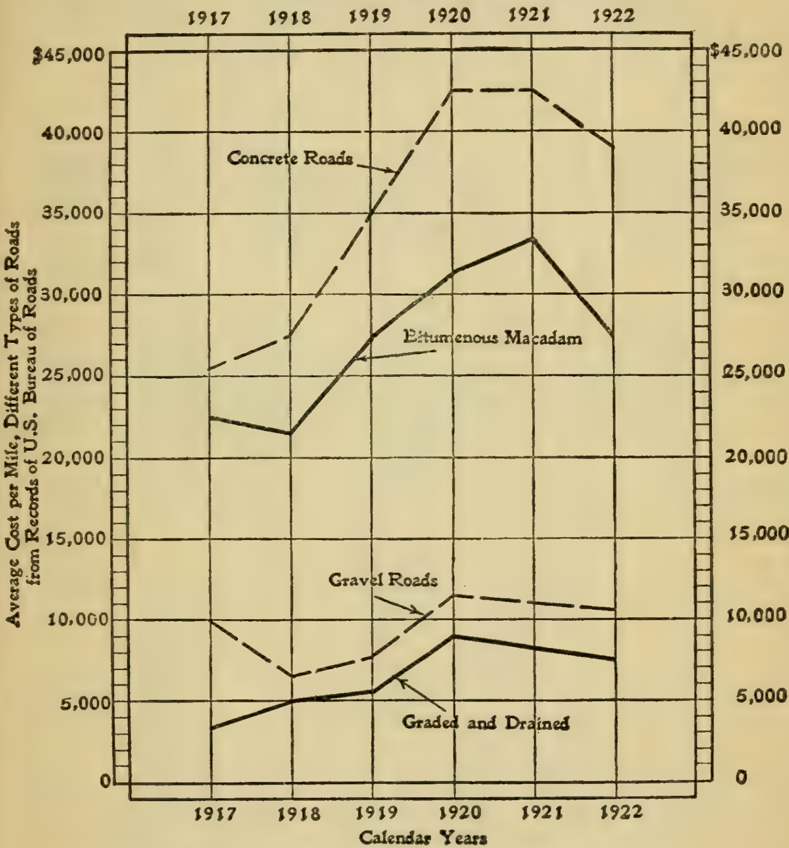
1. They provide lines of communication to all parts of the district and save time of travel.
2. They provide direct-contact hauling service to all parts of the producing area of the district for the entire year.
3. They make rural life more attractive and tend to stabilize a healthy ratio of rural and city population.
4. They increase the social and recreational possibilities of both city and rural residence.
5. They increase the flexibility and the strength of the general transportation system of the county in times of unusual stress, such as military use in time of war and emergency transportation in case the railroad systems are tied up by strikes or otherwise.
6. They raise rural land values.
7. They increase the range of marketing in respect to both distance and favorable selling periods.
8. They promote suburban residence of city dwellers and reduce the necessity for congested living conditions.

Indirect General Benefits.—While it is impossible to put an exact money value on the indirect general benefits, it is certain that they are much more important than the item of reduced vehicle operation cost. It is also certain that the indirect benefits alone more than justify the construction of a complete system of modern highways usable the year round for moderate loads with moderate comfort and safety. Roads of this class will be termed "general-utility highways." Their value consists primarily in complete mileage and in their ability to handle the normal business and pleasure traffic of the community the year round. This value is not directly proportional to the volume of traffic, nor does it depend on extreme refinements of pavement surface, grades, and alignment in order to give perfection in travel comfort and to reduce motor operation costs to a minimum. These highways reduce motor operation costs in a varying degree, depending on the type of pavement and on the grade reductions necessary for general-utility purposes. No attempt should be made to reduce the cost of vehicle operation below that obtained by the normal utility standards for construction or reconstruction programs financed by general tax levies. Where such programs are financed by direct vehicle taxation, increased standards of construction may be justified by the increased direct saving to traffic, but even under such programs it is desirable to scrutinize the relation of proposed cost to value

and to limit improvements over and above utility standards to amounts justified by actual traffic money savings.

The alignment, grading, bridges, safety provisions, and type and width of pavements required to fulfil the functions of general-utility roads vary for different volumes of traffic and for the cost and availability of different kinds of road materials, and should be

TYPICAL HIGHWAY COSTS



selected so that the final yearly cost of the highways is kept to a minimum. This cost includes interest on construction investment, maintenance, and renewal charges.

Table 2 summarizes the requirements for general-utility highways serving different volumes of traffic. This table has a quite universal value, as it is based on the experience of engineers over a long period.

TABLE 2.—GENERAL SLIDING SCALE OF MINIMUM SPECIFICATIONS TO MEET TRAFFIC NECESSITIES

Item	Pioneer roads Class IV, less than 100 vehicles daily year-round average	Agricultural roads Class IV, less than 300 vehicles daily average	General-utility roads Class III, 300–800 vehicles daily average	Detail data index page No.
Right of way	100′	50′ minimum	60′ minimum	177
Culverts:				
Type	Semipermanent	Semipermanent	Permanent	212
Loads	H-13–H-15	H-13–H-15	H-15	200
Roadway width	Normal	Normal	Normal	203
Bridges:				
Type	Semipermanent	Permanent	Permanent	205
Loads	H-13–H-15	H-13–H-15	H-15	200
Roadway width, feet	12–18	20	22	203
Bridge sidewalks	None	None	None	203
Grades:				
Maximum	5–10%	5–8%	5–8%	105
Minimum	0.3%	Level	Level	109
Intermediate	No reduction	No reduction	No reduction	106
Compensation for alignment	3% on 40′ radius; 4% on 80′ radius	Compensate	Compensate	118
Alignment:				
Normal maximum curvature	100′ radius (40′ radius minimum)	250′ radius	500′ radius	120
Minimum at right-angle curves (in open country)	100′	100–200′ radius	250′ radius	120
Minimum on steep grades (5% or steeper)	100′ radius	300–400′ radius	500–600′ radius	120
Roadway sections:				
Width grading, feet	10–30	20–30	22–36	155
Width pavement, feet*	8–12	8–12	15–18	130
Width hard shoulders	No special provision	No special provision	18–20	130
Turnouts	Provided	None	None	164

Pavements:				
General types	Natural or selected soil	Selected soil, sand clay-gravel or macadam	Gravel or macadam	40
Safety provisions:				
Sight distance, feet	No limit	250	300	114
Guard rail	Some wooden rail	Wooden rail	Concrete posts or cable rail	676
Banked curves	Needed	Needed	Needed	124
Pavement marking (traffic lanes)	None	None	None	698
Railway crossing protection	Warning signs	Warning signs	Automatic signals	599
Pedestrian traffic	No provision	No provision	No provision	177
Danger signs	Provided	Provided	Provided	687
Direction signs	Provided	Provided	Provided	687
Illumination	None	None	None	699
APPROXIMATE TYPICAL COSTS PER MILE OF ROAD (1925 COST CONDITIONS) (Including bridges and grade crossing protection as listed above)				
Typical costs per mile for original construction	\$1,000–\$25,000	\$10,000–\$15,000	\$15,000–\$30,000	16
Approximate yearly cost of maintenance plus approximate yearly cost of renewal	20– 200	600 ±	1,400 ±	66
Total approximate yearly costs including interest on first cost maintenance and renewal	100– 1,400	1,200 ±	2,500 ±	66
Approximate yearly saving to traffic over earth-road conditions per vehicle mile	Development roads, impossible to figure	0.01 ±	0.015 ±	14
Approximate yearly saving to traffic per mile of road for average volume different classes of traffic	Development roads, impossible to figure	700 ±	3,200 ±	

* NOTE.—These widths are for straight alignment. For extra width on curves see page 132.

TABLE 2—*Continued*

Item	General-utility roads		Main rural roads, metropolitan districts, over 6000 vehicles daily	Detail data index page No.
	Class II, 800–2000 vehicles daily average	Class I, 2000–6000 vehicles daily average		
Right of way	70′ minimum	80′ minimum	80–100′ minimum	177
Culverts:				
Type	Permanent	Permanent	Permanent	212
Loads	H-15	H-20	H-20	200
Roadway width	Normal	Normal	Normal	203
Bridges:				
Type	Permanent	Permanent	Permanent	205
Loads	H-15	H-20	H-20	200
Roadway width, feet	22–24	24–30	30–40	203
Bridge sidewalks	As needed	Sidewalk	Sidewalk	203
Grades:				
Maximum	5–7 %	5–6 %	5 %	105
Minimum	Level	Level	Level	109
Intermediate	No reduction below 4 %	No reduction below 3 %	No reduction below 3 %	106
Compensation for alignment	Compensate	Compensate	Compensate	118
Alignment:				
Normal maximum curvature	500′ radius	600′ radius	800′ radius	120
Minimum at right-angle curves in open country	300′ radius	400′ radius	400′ radius	120
Minimum on steep grades (5 % or steeper)	500–600′ radius	600–800′ radius	800–1,000′ radius	120
Roadway sections:				
Width grading, feet	24–36	32–40	45–54	156
Width pavement, feet*	16–18	18–20	27–36	130
Width hard shoulders	20–24	22–27	36–45	130
Turnouts	None	None	None	164

Pavements:				
General types	Macadam or rigid types	Rigid types	Rigid types	40
Safety provisions:				
Sight distance, feet	350	350	400	114
Guard rail	Concrete posts or cable rail	Cable rail or solid wall	Solid wall	676
Banked curves	Provided	Provided	Provided	124
Pavement marking (traffic lanes)	As needed	Provided	Provided	698
Railway crossing protection	Automatic signals or eliminations	Eliminations	Eliminations	599
Pedestrian traffic	As needed	Sidepaths	Sidewalks	177
Danger signs	Provided	Provided	Provided	687
Direction signs	Provided	Provided	Provided	687
Illumination	None	As needed	Provided	699

APPROXIMATE TYPICAL COSTS PER MILE OF ROAD (1925 COST CONDITIONS)
(Including bridges and grade crossing protection as listed above)

Typical costs per mile for original construction	\$30,000–\$50,000	\$70,000–\$90,000	\$140,000 ±	16
Approximate yearly cost of maintenance plus approximate yearly cost of renewal	2,000 ±	3,000 ±	4,000 ±	66
Total approximate yearly costs including interest on first cost maintenance and renewal	4,000 ±	6,600 ±	11,000 ±	66
Approximate yearly saving to traffic over earth-road conditions per vehicle mile	0.017 ±	0.02 ±	0.02 ±	14
Approximate yearly saving to traffic per mile of road for average volume different classes of traffic	7,500 ±	28,000 ±	60,000 ±	

* NOTE.—These widths are for straight alignment. See page 132 for extra width on curves.

TABLE 3.—APPROXIMATE NECESSARY CONSTRUCTION COSTS GENERAL UTILITY HIGHWAYS (WESTERN NEW YORK) (1925 cost conditions)

Approximate average number of vehicles per day (24 hr.), average mixed traffic	Approximate average construction cost per mile		
	Grading, culverts, pavement, and minor incidentals	Bridges over 5′ span	Railroad grade-crossing eliminations, one every 5 miles
0– 300	$ 5,000–$15,000	$ 3,000 ±	15,000 ±
300– 800	15,000– 30,000	4,000 ±	20,000 ±
800–2,000	30,000– 50,000	5,000 ±	20,000 ±
2,000–6,000	50,000– 70,000	6,000 ±	25,000 ±

Table 3 costs include grading, drainage, and pavement. For the ordinary road where the grade line follows the natural surface, the item of grading is largely necessary to provide a suitable roadbed for the pavement and is properly a pavement charge. Where hills are cut down and distance shortened, the economic value of such work (see Tables 5 and 6, p. 12) should be added to the values given in Table 7 before comparing with Table 3.

Table 3 summarizes typical average costs of a large mileage of general-utility highways under different volumes of traffic in western New York for 1925 cost conditions. Grade-crossing eliminations are not strictly an integral part of this type of highway and are discussed as a special problem in Chap IX. Table 3 will vary for different localities depending on soil conditions, local road materials, necessary bridge replacements,[1] and local contract costs. Tabulations of this general character are the first necessary step in the rational comparison of highway costs and value for any specified district.

Direct Reduction in Cost of Vehicle Operation.—The service value of highways in respect to reduction in the cost of vehicle operation depends on the volume and character of the traffic and on the reduction in cost of operation per vehicle mile. All of these factors are subject to considerable uncertainty, but the data now at hand make it possible to arrive at reasonable general conclusions, although they are not yet sufficiently definite to warrant hair-splitting decisions upon the details of design.

Methods of estimating present and probable future traffic are discussed in detail under Traffic Volume (p. 32). For this part of the discussion it is necessary to consider only the relation of business to pleasure traffic in arriving at reasonable allowances for highway value to the community at large and to individual traffic operations. The very complete Connecticut Traffic Census taken under the joint cooperation of the state and the U. S. Bureau of Public Roads in 1922 showed that 65% of the passenger autos can be classed as pleasure traffic and 35% as business traffic. Western New York investigations indicate that about 50% of the vehicles on the main state road system are pleasure and 50% business traffic. As the community at large derives no direct tangible business benefits

[1] Bridge contracts for the United States, 1920 to 1925, amount to 15% of cost of road and street contracts.

from the reduction of motor operating costs on private pleasure trips, the author has been in the habit of using one-half of the total traffic counts in computing the money saving of improved highways to the community at large and the total traffic in computing the money value of highways to vehicle owners.

This means that for general-utility highway construction financed by general tax levy it is probably reasonable to figure only one-half of the justifiable expenditure that can be figured for reconstruction boulevard construction financed by direct vehicle taxation.

Detail motor operation costs are given in Chap. XV, Cost Data. Table 4 (p. 11) gives a rough approximation of the relative cost of motor operation on different types of road improvements. Table 5 gives an approximation of the relative capitalized cost of motor operation on different grades. Table 6 gives the same data modified for business operation only. The total value of improvements includes all reductions in motor operation costs due to shorter distance, reduced grades, and a better type of pavement.

(text continued on page 14.)

TABLE 4.—RELATIVE COSTS OF VEHICLE OPERATION ON VARIOUS CLASSES OF ROADWAY SURFACES[1]

Type of surface	Type and speed of vehicle			
	Solid-tire trucks, 10 m.p.h.	Pneumatic-tire trucks, 15 m.p.h.	Automobiles, 25–35 m.p.h.	Motor busses, 25 m.p.h.
	Cents per ton-mile	Cents per ton-mile	Cents per vehicle mile	Cents per ton-mile
Average Portland cement concrete and asphalt-filled brick	8.00	8.30	10.00	24.00
Best Portland cement concrete and asphalt-filled brick	7.75	7.70	9.30	22.50
Best gravel, yearly average	8.50	8.80	10.90	25.70
Ordinary gravel, yearly average	9.00	9.40	11.80	27.80
Water-bound macadam, well maintained	8.70	8.95	11.10	26.00
Bituminous macadam, well maintained	8.50	8.80	10.60	25.70
Average sheet asphalt, yearly average temperature	8.10	8.30	10.00	24.00
Average asphaltic concrete, yearly average temperature	8.00	8.30	10.00	24.00
Best earth, well packed by traffic, yearly average	9.20	9.50	12.00	27.80
Ordinary earth with light traffic, yearly average	9.50	9.95	12.60	29.60

[1] AGG, T. R., and CARTER, H. S., in cooperation with U. S. Bureau of Public Roads, *Bull.* 69, Iowa State College, July, 1924. See also p. 68 for discussion of operating costs on different surfaces and the capitalized value of reductions in vehicle operation costs by different kinds of high-class pavement construction.

TABLE 5.—APPROXIMATE CAPITALIZED COST AT 5% OF OPERATING 100 MOTOR VEHICLES DAILY (36,500 PER YEAR) FOR 1′ OF DISTANCE ON THE VARIOUS GRADES[1]
(Time factor included)

Rate of grade	1 Average traffic trucks and light vehicles, based on 11 cts. per mile average grades	2 Light motor vehicles, based on 8 cts. per mile average grades	3 Heavy commercial trucks, based on 40 cts. per mile average grades
Level	$14.80	$10.70	$54.00
1	14.80	10.75	54.00
2	15.10	10.85	54.60
3	16.10	11.05	56.70
4	17.90	11.40	63.90
5	20.50	12.00	74.10
6	23.30	12.90	84.50
7	26.40	14.50	95.00
8	29.60	16.15	105.60
9	32.80	17.90	116.20
10	36.00	19.70	127.00

NOTE.—This table to be used only for rough general comparisons of the relative value of alternate long routes. The actual costs must be used with caution. Alignment good. For effect of dangerous alignment, see page 118.

[1] "Highway Location, Grading and Drainage," McGraw-Hill Book Company, Inc.

TABLE 6.—APPROXIMATE CAPITALIZED COST AT 5% OF OPERATING 100 MOTOR VEHICLES DAILY (36,500 PER YEAR) FOR 1′ OF DISTANCE ON THE VARIOUS GRADES[1]
(Time factor modified columns 1 and 2. Fuel cost not considered for 50% of light motors columns 1 and 2)[2]

Rate of grade	1 Local service roads and secondary state routes, less than 1800 vehicles daily average	2 Main intercity state roads, probable future traffic 1800 or more daily average	3 Future commercial truck to 11 roads
Level	$ 9.10	$12.20	$ 54.00
1	9.10	12.20	54.00
2	9.15	12.30	54.60
3	9.25	12.50	56.70
4	9.40	12.80	63.90
5	9.70	13.50	74.10
6	10.20	14.50	84.50
7	11.20	15.80	95.00
8	12.50	17.70	105.60
9	14.00	19.80	116.20
10	15.50	22.00	127.00

NOTE.—As a general rule, make no changes in existing locations or grade lines which fit the natural surface unless the saving in approximate operating cost is at least twice the additional cost of construction. This note does not apply to changes which are desirable to improve the safety or convenience of the road.

[1] "Highway Location, Grading and Drainage," McGraw-Hill Book Company, Inc. This table serves as a practical basis of comparison of alternate routes or alternate grading designs. (See p. 57 for a detailed tabulation showing the method of using these data.)

[2] U. S. Bureau of Public Roads Traffic Census in Connecticut, 1922, showed that 65 % of the passenger autos were pleasure vehicles and 35 % business vehicles.

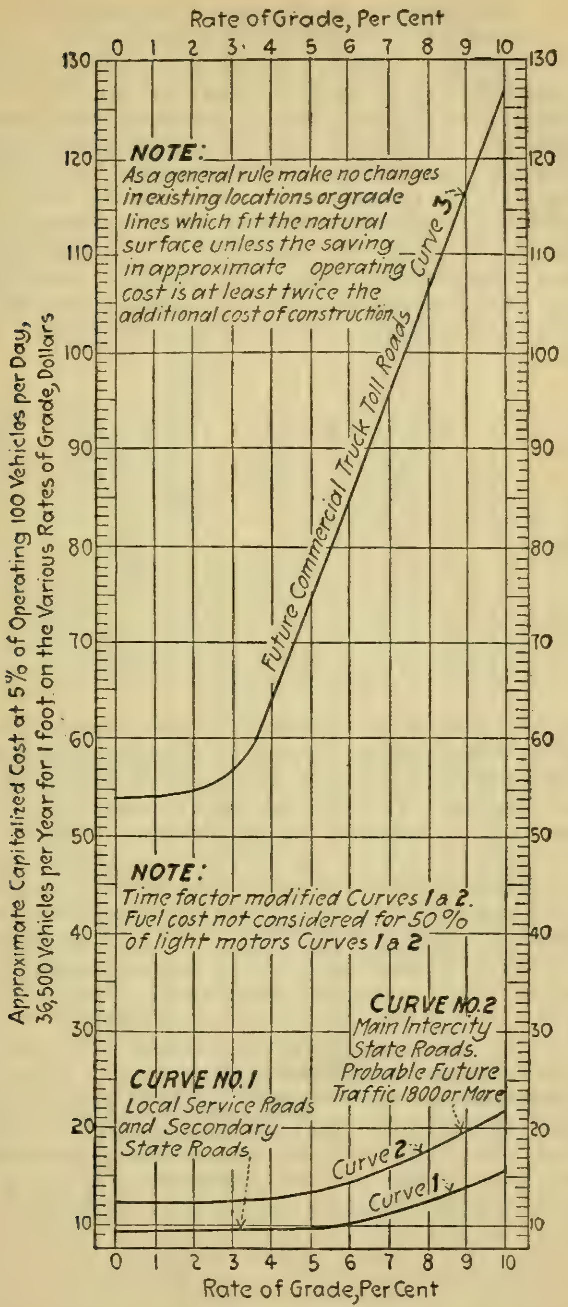


FIG. 2.—Graph of Table 6. A practical basis of comparison of alternate routes or alternate grading designs. This graph assumes one-half of traffic uphill and one-half downhill.

Figures of this kind must, of course, be used with caution. They do not consider the effect of snow and ice for a portion of the year, nor do they consider the gradual deterioration of the higher-type surfaces which tend to reduce the apparent advantage of the higher types. Table 4 also shows considerably more difference between well-maintained modern macadams and rigid pavements than the author's experience indicates (see p. 68). Considering all these factors and the facts that the more important roads are better located, better graded, better maintained, and are kept free of snow in winter, the author has been in the habit of using the following values for saving in average vehicle operation per mile for different classes of general-utility road improvements as listed in Table 2 (p. 6) over and above earth-road conditions.

CLASS OF ROAD

	Class I, over 2,000 vehicles daily, in cents	Class II, 800 to 2,000 vehicles daily, in cents	Class III, 300 to 800 vehicles daily, in cents	Class IV, less than 300 vehicles daily, in cents
Total value to vehicle owners	2 per vehicle mile	1.7 per vehicle mile	1.5 per vehicle mile	1 per vehicle mile
Approximate value to community at large	1	0.8	0.7	0.5

If justifiable road cost is considered strictly from the standpoint of reduction in vehicle operation cost, the above savings per year per mile of road must at least pay for the yearly maintenance, renewal, and interest charges of the highway improvement.

Anticipating the discussion of maintenance and renewal, the yearly road cost for interest on construction, maintenance, and renewal depends largely on the volume of traffic and is only slightly affected by the type of pavement, provided the pavements used are of the general class indicated in Table 2. This yearly charge ranges from 7 to 12% of original cost of the improvement for general-utility highways and averages about 10%. This, of course, is subject to some variation, but is not misleading for purposes of arriving at the extreme justifiable maximum expenditure for construction for a large mileage of improved roads. This maximum justifiable expenditure is, therefore, approximately 10 times the resultant saving to traffic from the improvement. If the community desires any real return on its investment it is well not to exceed two-thirds of the maximum amount. Table 7 is compiled on this basis, assuming a saving of 1 ct. per vehicle mile.

TABLE 7.—ALLOWABLE COSTS
(1921 cost conditions)

Average daily number of vehicles	Assumed yearly travel cost saving, based on 1 ct. per vehicle mile, average mixed traffic	Maximum allowable expenditure per mile for original construction, based on pavement benefit	Reasonable expenditure with some profit to the community
100	$ 350	$ 3,500	$ 2,300
200	700	7,000	4,600
300	1,050	10,500	6,900
400	1,400	14,000	9,200
500	1,750	17,500	11,500
600	2,100	21,000	13,800
700	2,450	24,500	16,100
800	2,800	28,000	18,400
900	3,150	31,500	20,700
1,000	3,500	35,000	23,000
1,500	5,250	52,500	34,500
2,000	7,000	70,000	46,000
3,000	10,500	105,000	69,000
4,000	14,000	140,000	92,000
5,000	17,500	175,000	115,000
10,000	35,000	350,000	230,000

Column 3 represents maximum allowable expenditure. If construction equals this amount, the community gets no money return on their investment; they merely take their money out of one pocket and put it in the other. It is, therefore, not desirable to use more than two-thirds of these amounts if a profit is considered desirable; column 4 has been figured on this basis.

Figure 3 compares graphically the necessary and allowable construction costs per mile for general-utility highways based on a saving of 1 ct. per average vehicle mile. Comparisons of this kind, making due allowance for the degree of improvement accomplished and the method of financing, usually indicate the following general conclusions:

1. On roads carrying an exceptionally heavy traffic, the actual travel saving will more than justify high-grade types of construction.

2. For moderate traffic (say, 300 to 1500 average vehicles per day) satisfactory general-utility highways are justified, but needless refinements may well be avoided if any real return on investment is desired.

3. For purely local roads carrying less than, say, 300 to 500 vehicles per day it is probably necessary to consider the intangible benefits to justify a satisfactory standard of construction. This is shown in chart form on page 16 and begins to help in the matter of tax burden distribution.

Summarizing the limitations imposed on expenditures by the value of highways: If Fig. 3 is modified slightly to fit actual observed road service, it is evident that if construction investment is considered from the standpoint of direct return by reduction in cost of vehicle operation, we are limited to the standard of general utility except for heavy-traffic roads carrying an average volume of over, say, 1500 vehicles per day. This class of road represents a very small percentage of the total road mileage. Even for roads

carrying a year-round average of more than 1500 vehicles per day, there is no particular advantage in adding much to the amounts shown by the general-utility curve.

If construction investment is considered from the standpoint of intangible benefits expressed in terms of convenience, safety,

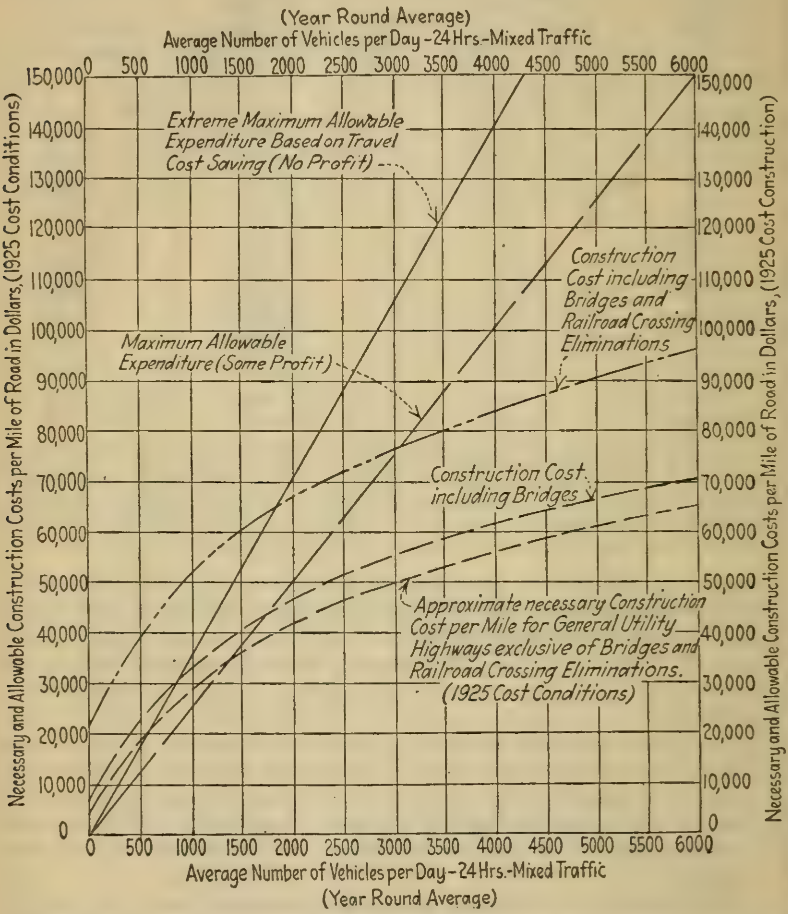


FIG. 3.—Comparison of approximate necessary and allowable construction costs for general utility roads in Western New York under different volumes of traffic. (Construction costs for 1925 conditions. Allowable costs based on 1 ct. per vehicle mile benefit.)

pleasure, and ease of communication, no practical limitation of expenditure except that imposed by the community's financial ability to complete a general-utility system within a reasonable time need be considered.

The tax burden distribution also has a distinct bearing on the proper limitation of expenditure; that is, if the roads are being improved by means of a general tax levy it is desirable not to exceed

the costs required by general-utility standards. If the road funds are raised by direct vehicle taxation more liberality in expenditures is justified for added convenience and pleasure.

2. Distribution of Tax Burden.—A successful tax is based on three main points:

1. The final burden should fall on each individual as nearly as possible in proportion to the direct and indirect benefit received.

2. The direct tax should be paid by the individuals receiving the immediate direct benefit if they are financially able.

3. The tax must be levied on a definite source comparatively easy to assess and be collected from individuals having the ready money for payment.

Real property, motor vehicles, tractor and horse vehicles, and gasoline are definite sources of taxation owned or used by individ. uals, presumably with ready cash to pay any reasonable tax burden-

The immediate and direct benefits of improved highways are largely received by the owners of vehicles operating on the roads.

The final direct and indirect benefits of a modern highway system were given on page 3.

While the road user gets most of the direct benefit, it is rarely feasible in the first stages of the improvement to tax him directly for a large proportion of the cost of construction; that is, before improved highways are an accomplished fact, the vehicles are fewer in number and operated by financially poorer individuals. The completion of a modern highway system increases the number and effectiveness of vehicles and adds to the ability and willingness of the owners to assume a larger tax burden. It is, therefore, generally believed that the original construction of such a modern general-utility system (under a proper classification based on reasonable regulation of traffic) should properly be paid for largely by a general tax levy, which is eventually quite evenly distributed over the community.

The cost of maintenance and the renewal of pavements depend on the volume and kind of traffic. The largest share of the benefit of keeping a road continually in excellent shape goes to the vehicle owner. There are two general classes of traffic: pleasure traffic and business traffic. If a pleasure vehicle is taxed a fair amount to cover the damage it does to the road, this is a luxury tax borne by the owner. If a business vehicle is taxed a fair amount to make the highway self-supporting, the charge is added to the other vehicle operating costs which go into the price charged to the consumer, and the public at large foots the bill. The principle of a vehicle tax for maintenance and renewal apparently has a sound basis in fairness. While there may be minor flaws in its application, there are the same flaws in the application of a tax principle which is not essentially sound, so that the small practical inequalities of the tax do not invalidate the soundness of the general proposition.

It is certain that if maintenance and renewal were paid by general tax levy pleasure traffic would escape its fair luxury tax and the business traffic, particularly heavy hauling, would have an unfair advantage in competition with other transportation methods which pay their own cost of track or waterway construction and maintenance.

Public-road tolls are not feasible except for a few special cases, as they restrict the free movement of traffic, so that some form of graduated vehicle license based on gross vehicle weight and type of tire supplemented by a gasoline tax seems the most reasonable form of tax for the upkeep and renewal of at least the main highways.

These general principles expressed in terms of definite policy are as follows:

It is quite generally recognized that the intangible benefits of a road system practically obligate the community at large to construct such roads up to the standards of general utility by means of a general tax levy. This can be accomplished without exceeding the bounds of reason on the basis of a fairly reasonable length of time for the construction program and the use of reasonable length of term of serial bonds for raising construction funds.

The direct and intangible benefits accruing to vehicles using the highways practically warrant putting upon the owners of vehicles the cost of maintaining and renewing at least the main roads of such a system after it has once been built. For the purely local roads which are not self-supporting due to light volume of traffic (see p. 15), it is not reasonable to tax vehicles for their entire maintenance and upkeep; that is, vehicle license fees plus gasoline tax should probably be figured on the basis of taking entire care of the main roads, aggregating not over 15 to 25% of the total road mileage, and for raising the standard of such roads beyond that of general utility. For the purely local roads a small percentage of the maintenance cost can be properly charged against traffic. This can be accomplished by a graduated license fee and gas tax not beyond the bounds of reason. For a completed system in a well-settled area, it is probable that an average yearly tax of from \$25 to \$50 per vehicle will produce the necessary funds. Considering the mileage run by the average car, 4000 to 7000 miles per year with a yearly gas consumption of from 400 to 600 gal. per registered vehicle and the variations in license fees increasing rapidly for commercial trucks, this would not be an excessive amount.

Average Cost of Maintenance and Renewal per Vehicle Mile
(Western New York conditions)

Class of traffic	Average daily number of vehicles	Average yearly cost road maintenance and renewal for vehicle mile, cents	Average cost for interest on original construction cost plus maintenance and renewal, cents
Class I	4,000	0.2	0.3
Class II	1,500	0.3	0.6
Class III	600	0.5	0.8
Class IV	200	0.7	1.4

The raising of funds for immediate temporary traffic service over the gaps in the existing improved road system may well be raised by

a slight addition to the vehicle tax; this affords no difficulties, as the immediate return to traffic is so self-evident that road users generally are in favor of such procedure. This tax gradually decreases as the system is completed, balancing the normal increase in the regular maintenance tax.

While it seems reasonable to care for the maintenace upkeep of the purely local roads by a yearly general tax levy, this is the most difficult part of the program from a practical standpoint. In the richer well-settled states it is not probably an excessive burden, but for the poorer districts it is likely that some help from some other source will be necessary. In such districts it is likely that it will be necessary to get along for some time with comparatively unsatisfactory conditions on the purely local roads.

The essential fairness of the road tàx depends on a proper equalization of value on the assessment roll and a well-thought-out graduated vehicle tax. It is desirable to avoid rapid fluctuations in the tax rate. This can be accomplished in the matter of vehicle licenses and gasoline tax by gradually increasing them from year to year as the improved roads grow in scope and service (see p. 21). It can be accomplished in the matter of general tax levy for construction by adopting a reasonable term of years for the construction program and issuing the serial bonds only as fast as actually needed for raising construction funds (see pp. 22 and 23).

In order to apply the foregoing principle of taxation definitely to any specific road program, it is necessary to determine the point in any policy of progressive road improvement where the roads have reached the limit properly chargeable to general taxation and beyond which limit further improvement is a strict traffic charge. This occurs when the general road system serves the majority of the individual users for ordinary business and local pleasure purposes as shown in Table 2 (p. 6), and when further improvement is for the added convenience of specially heavy commercial trucking on secondary roads or for the extreme convenience of pleasure traffic. To arrive at any reasonable definite conclusion, the general character and range of normal traffic must be considered (see p. 27 for the formulated conclusion).

3. Financing.—There are three general classes of highway expenditure which require different methods of financing:

1. Extensive programs involving comparatively permanent types of roads and bridges which are immediately needed in order to open up new territory or to handle ordinary business traffic economically are usually financed by the sale of serial or sinking-fund bonds.

2. Yearly maintenance or temporary makeshift improvements must be financed by yearly "pay as you go" tax budgets.

3. The reconstruction of fairly suitable existing highways up to more luxurious standards should usually be financed by yearly "pay as you go" tax budgets, although short-term bonds are sometimes allowable.

Construction funds for extensive programs are generally raised by serial or sinking-fund bonds. The "pay as you go" yearly appropriation policy is sometimes used for small programs, as it is the cheapest in final cost, but for an extensive program the bond

(text continued on page 24.)

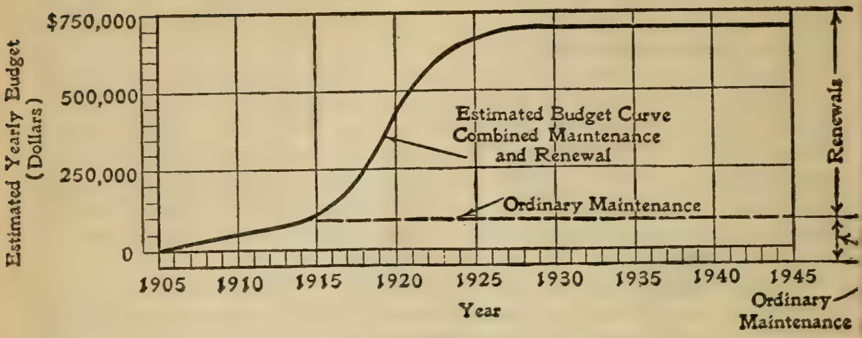


FIG. 19*A*.—Estimated yearly combined maintenance and renewal budget (1921 costs conditions).

Class I and II*A* roads (310 miles).

Assumed construction period 1905 to 1915.

Assumed life of pavement 12 to 15 years.

Note how the curve steepens up when pavement renewals becomes necessary and then flattens out to a high level line when the entire system is old enough for the renewal charge to become constant.

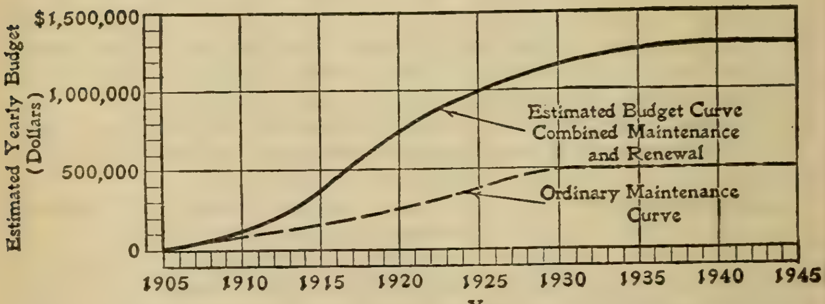


FIG. 19*B*.—Estimated yearly combined maintenance and renewal budget (1921 cost conditions).

Class II and III roads (1040 miles).

Assumed construction period 1905 to 1930.

Assumed life of pavement surface 8 to 12 years.

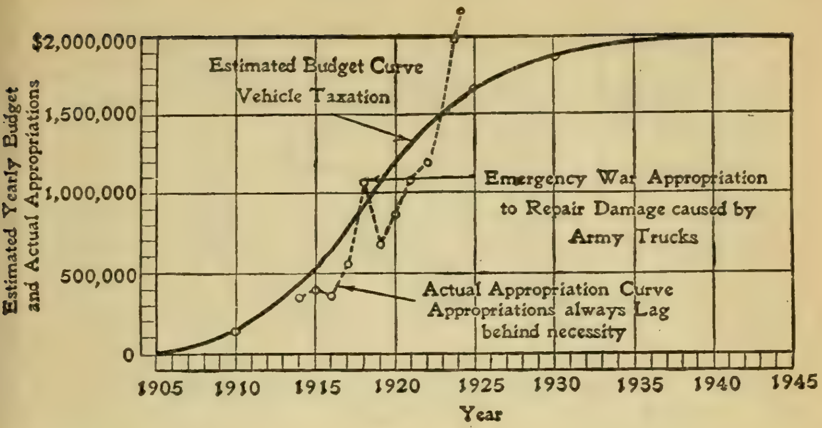


FIG. 19*C*.—This figure combines 19*A* and 19*B* and includes Classes I, II*A*, II and III roads.

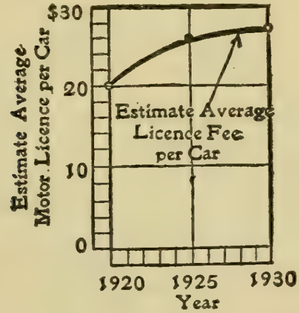
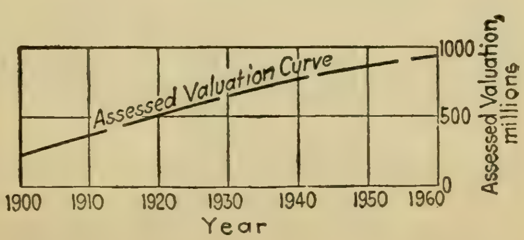


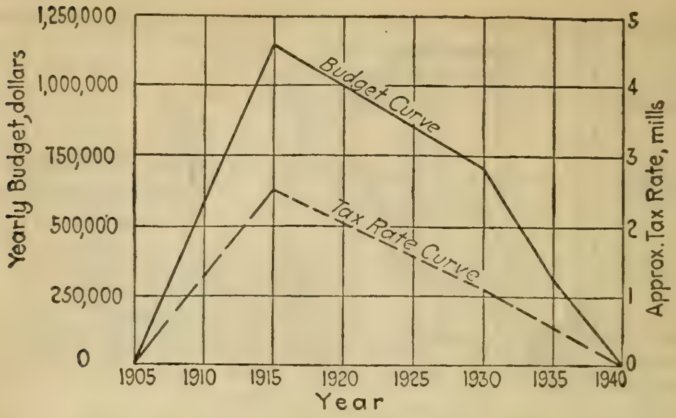
FIG. 19*D*.—Estimated necessary auto license fee.

FIG. 19.—Diagrams representing estimated combined maintenance and renewal yearly appropriations for District No. 4, Western New York.

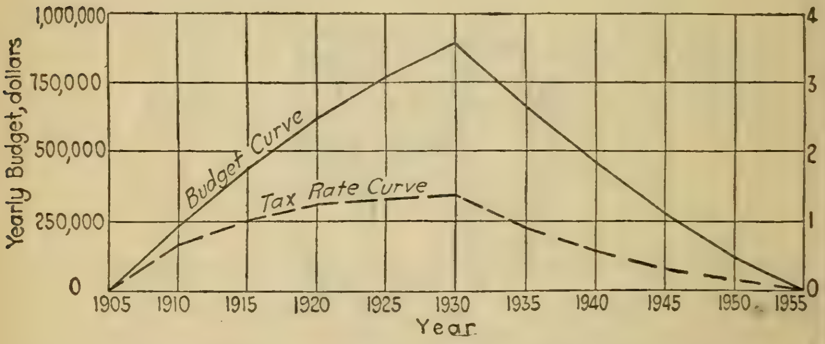
NOTE.—These appropriations should be raised by vehicle taxation. This data compiled in 1920 by W. G. Harger in connection with a personal study of Division No. 4 under assumed conditions to illustrate the value of classification in connection with a general finance plan. This same method can be applied to any program at any stage of procedure provided the data is carefully worked out considering the age and type of existing pavements.



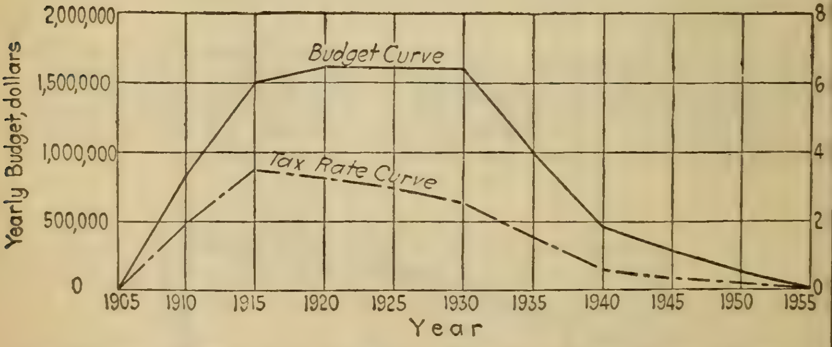
Estimated Assessed Valuation. Division 4.



Tax Curve for Construction Class I and II*A* Roads. Division 4.



Tax Curve for Construction Class II and III Roads. Division 4.



Tax Curve Class I, II*A*, II and III Roads. Construction Program

FIG. 20.

NOTE.—See page 25 for tabulation of budget.

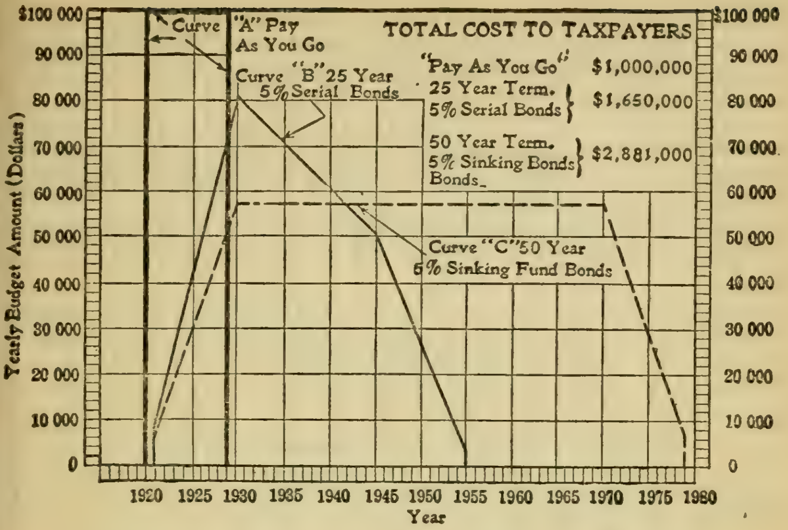


FIG. 4*A*.—Cost of different methods of financing.

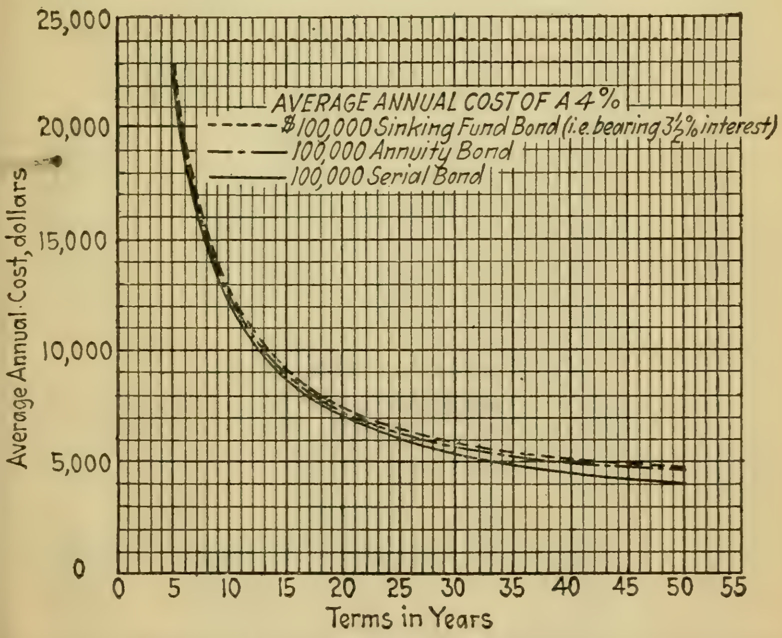


FIG. 4*B*.—Effect of term and kind of bond on average yearly repayment amounts.

method is to be preferred, as it permits more rapid construction, makes it possible to develop a more stable engineering organization, reduces rapid fluctuation of tax rates, and throws a fair share of the burden on to the future (for comparison of total and yearly cost, see Fig. 4, page 23).

Serial bonds are in more favor than the sinking-fund method, as the history of public sinking-fund bonds is not encouraging; the necessary yearly appropriations are often neglected and the sinking fund not well administered.

A reasonable term of bond depends on the rate of depreciation of the road improvement and on the maximum tax rate the community can afford.

An examination of Fig. 4*A* shows that the yearly tax budget charge for retiring bond issues does not lessen much for a bond term of more than 30 years. Considering the fact that the total cost of bond financing increases with the length of the term (see Table 7) and that the yearly charge does not decrease much for the longer terms, it is evidently desirable not to exceed the 25- or 30-year term. The 25-year serial bond method of raising funds for original improvement of highways seems to meet the requirements of the usual situation for the following reasons:

TABLE 7*A*.—TOTAL COST OF SINKING-FUND BOND

(Total cost of a $100,000 sinking-fund bond bearing 3, 4, 5, or 6% interest, with sinking fund drawing 3½%, and maturing at different periods from 5 to 50 years)

Terms in years	3 %	4 %	5 %	6 %
5	$108,241	$113,241	$118,241	$123,241
10	115,241	125,241	135,241	145,241
15	122,738	137,738	152,738	167,738
20	130,722	150,722	170,722	190,722
25	139,185	164,185	189,185	214,185
30	148,114	178,114	208,114	238,114
35	157,494	192,494	227,494	262,494
40	167,309	207,309	247,309	287,309
45	177,540	222,540	267,540	312,540
50	188,169	238,169	288,169	338,169

TOTAL COST OF SERIAL BOND

(Total cost of a $100,000 serial bond bearing 3, 4, 5, or 6% interest and maturing at different periods from 5 to 50 years)

Terms in years	3 %	4 %	5 %	6 %
5	$109,000	$112,000	$115,000	$118,000
10	116,500	122,000	127,500	133,000
15	124,000	132,000	140,000	148,000
20	131,500	142,000	152,500	163,000
25	139,000	152,000	165,000	178,000
30	146,500	162,000	177,500	193,000
35	154,000	172,000	190,000	208,000
40	161,500	182,000	202,500	223,000
45	169,000	192,000	215,000	238,000
50	176,500	202,000	227,500	253,000

The rate of depreciation of the different general kinds of modern highways is approximately as follows, assuming that the maintenance is moderately good and that the pavements are well designed and used under a volume of traffic for which they are suited (see Table 2, p. 6).

Road improvements include grading, drainage, pavement foundation, pavement surface course, and incidentals. The first three items are practically permanent. The surface and incidentals require renewals at quite regular intervals. Double-track macadam surfaces cost about 40% of the total cost of original improve-

Table 8.—Tabulation Illustrating Method of Figuring Yearly Budget. Serial Bond Financing

(25-year bonds 5% interest)

Year	Bonds issued to date	Outstanding indebtedness	Annual charges		
			Interest[1] 5 %	Repayment[2] account	Budget for year
1905	$ 1,400,000	$ 1,400,000			
1906	2,800,000	2,744,000	$ 70,000	$ 56,000	$ 126,000
1907	4,200,000	4,032,000	137,200	112,000	249,200
1908	5,600,000	5,264,000	201,600	168,000	369,600
1909	7,000,000	6,440,000	263,200	224,000	487,200
1910	8,400,000	7,560,000	322,000	280,000	602,000
1911	9,800,000	8,624,000	378,000	336,000	714,000
1912	11,200,000	9,632,000	431,200	392,000	823,200
1913	12,600,000	10,584,000	481,600	448,000	929,600
1914	14,000,000	11,480,000	529,200	504,000	1,033,200
1915	....	10,920,000	574,000	560,000	1,134,000
1916	....	10,360,000	546,000	560,000	1,106,000
1917	....	9,800,000	518,000	560,000	1,078,000
1918	....	9,240,000	490,000	560,000	1,050,000
1919	....	8,680,000	462,000	560,000	1,022,000
1920	....	8,120,000	434,000	560,000	994,000
1921	....	7,560,000	406,000	560,000	966,000
1922	....	7,000,000	378,000	560,000	938,000
1923	....	6,440,000	350,000	560,000	910,000
1924	....	5,880,000	322,000	560,000	882,000
1925	....	5,320,000	294,000	560,000	854,000
1926	....	4,760,000	266,000	560,000	826,000
1927	....	4,200,000	238,000	560,000	798,000
1928	....	3,640,000	210,000	560,000	770,000
1929	....	3,080,000	182,000	560,000	742,000
1930	....	2,520,000	154,000	560,000	714,000
1931	....	2,016,000	126,000	504,000	630,000
1932	....	1,568,000	100,800	448,000	548,800
1933	....	1,176,000	78,400	392,000	470,400
1934	....	840,000	58,800	336,000	394,800
1935	....	560,000	42,000	280,000	322,000
1936	....	336,000	28,000	224,000	252,000
1937	....	168,000	16,800	168,000	184,800
1938	....	52,000	2,600	112,000	114,600
1939	....	0	0	56,000	56,000
1940	....	0	0	0	0
	....	....	$9,091,400	$14,000,000	$23,091,400

[1] Interest on outstanding indebtedness.

[2] Repayment account is 1/25 of bonds issued to date until principle is paid. For a 30 year term, repayment would be 1/30 of bond till principle was paid.

ment and generally last about 10 years before renewal is necessary; that is, for this class of improvement it is fairly safe to figure on a natural depreciation of 40% of the original investment in, say, 10 years, after which very little further depreciation occurs, as the balance of the work retains its value quite indefinitely if properly maintained. For rigid pavements, the surface course needs renewing in about 15 years as a rule, and this item amounts to about 40 to 60% of the cost of original improvement; that is, the depreciation is about 50 to 60% in 15 years. For any general system of highway improvements composed of macadams and rigid pavements, a bond term which results in paying off 40% of the principal and interest in 10 years and 60% in 15 years is probably sound financing; the 25-year (or less) bond complies with this condition.

Bridges and grade-crossing eliminations permit a maximum 40-year bond period.

For reconstruction of surfaces and yearly maintenance the "pay as you go" method financed by direct vehicle taxation for the main highways and by direct general tax levy for the purely local roads seems reasonable. If bonds are used for a reconstruction program to renew the pavement surfaces the bond term should probably not exceed 15 years, but this method is hardly warranted except in unusual cases.

Table 8 illustrates detailed computation of yearly tax budget for serial bond financing.

For a more complete discussion of Bond Financing see Location, Grading and Drainage of Highways, McGraw-Hill Book Company, Inc.

4. **Traffic Requirements.**—The shift in general mode of transportation from horse to motor is about completed. Horse traffic will not entirely disappear, but it is not a large factor in determining road policy in many localities. There are today (1926) approximately 18,000,000 motor vehicles in the United States, of which approximately 2,000,000 are trucks from ¾- to 7-ton capacity.

Motor traffic can be divided into three general classes:

1. The passenger car.
2. Light trucks and passenger bus lines.
3. Heavy commercial hauling trucks.

1. The light passenger car represents the largest part of the volume of road traffic, probably at least 85%. This type of traffic desires all-the-year-round roads which can be traveled at high speed with comfort, safety, and convenience. This kind of traffic does not require extreme strength of pavements, as the vehicles are light in weight, but it does require a fairly good surface comparatively free from dust.

2. The second class of traffic, namely, light trucks up to 2½-ton capacity and passenger bus lines, desires about the same general service as the light passenger cars except that the item of extreme comfort is not so important. They require somewhat stronger pavements to handle their loads the year round, but this requirement is not at all excessive and can be easily obtained on all the roads of a general-utility system without too much cost. Truck

traffic of this nature constitutes approximately 10% of the total road traffic today (1926) and represents the class of hauling equipment preferred by the individual engaged in farming, small-town business, parcel delivery, and general-utility hauling. Available information indicates that for the usual business man, farmer, and the parcel delivery of even large corporations the light $\frac{3}{4}$- to $2\frac{1}{2}$-ton trucks with pneumatic-tire equipment to at least the 1-ton size and probably to the 2-ton size will be the most popular type for hauling. This is due to reasonable first cost for the truck, moderate upkeep, high speed, comfort, and general utility.

Passenger cars, these light trucks, and what small amount of horse traffic still remains constitute at least 90 to 95% of the total number of vehicles using the roads; if the needs of these two classes of traffic are satisfied, the problem of giving complete service to the community at large is practically solved. *We can probably afford to build all the roads to satisfy 95% of the users without any restrictions in regard to load or reasonable speeds which would annoy the individual in the selection of his car or truck. This can be done with moderate-priced general-utility roads* (Table 2, p. 6).

3. The class of vehicle that gives trouble is the heavy commercial truck, which aggregates probably not over 5% of the total rural road vehicles, although for special roads they may run as high as 50% of the total volume. They require extremely strong high-priced, rigid pavements. The use of such trucks for moderately long hauls in competition with rail shipments is undoubtedly of considerable value to the community at large. How much it is worth and how much consideration should be given to this type in deciding on a general road policy is open to argument. It is quite generally conceded that the heavy truck seems to be the logical and popular means of intercity transportation of certain commercial products for moderately long hauls in competition with rail shipment, say 100 miles; but by reason of their greater cost per mile of operation they are not suited to make a large number of indlividual deliveries in successful competition with the small truck. They are, however, usefully employed for certain industries on colective routes, running on certain well-defined hauling arteries with definite stops at which the local shipments are picked up. For collecting milk, for instance, certain main-line roads through the heart of the producing district with collection stations at the crossroads will serve the purpose satisfactorily and economically. It is probable that if provision is made for strong pavements on the main natural commercial routes which aggregate not over 1 to 10% of total road mileage depending on the general character of the district, the community will derive about all the benefit possible from this class of hauling.

A general-utility system of highways consisting of a small mileage of heavy-truck roads and a large mileage suitable for passenger cars and light trucks seems to offer the most return on an investment in highways, as it in effect, gives the community about all of the advantages that it can derive from the system without unjustifiably large expenditure. Such a system can be properly constructed by general taxation, but if the secondary roads are increased in cost for the bene-

fit of heavy trucking, this added cost is not properly a general community charge and such additional cost should be paid by a traffic tax.

5. Traffic Regulation.—If the unregulated use of 5- to 7½- or 10-ton trucks over all the highways is permitted at all seasons of the year, a slight reduction in total hauling cost might result, but it would increase the first cost and maintenance of a general system out of all proportion to the added benefit in reduced hauling cost. (For the effect of different maximum loads on construction cost see Chap. VI, p. 425.) It is evident that, in order to get anywhere with a general system of roads within a reasonable term of years, some restriction must be placed on heavy-truck hauling. These restrictions should not be made any more severe than necessary, but reasonable restrictions in regard to load, speed, and range of travel are recognized as necessary. Restrictions on load and speed have already been accomplished, but restriction on range of travel has not yet been generally accomplished.

Present restrictions on improved roads do not usually permit over a 28,000-lb. gross weight (including weight of truck) and a wheel pressure not exceeding 800 lb. per inch width of tire (see Chap. VI, p. 370); existing statutes tend to limit the speed of solid-tire trucks to from 12 to 15 m.p.h. It is probably desirable to go a step further and limit the use of heavy trucks to specified hauling routes, and to limit the use of even the 5-ton truck to special hauling routes except in the dry season of the year. Statutory restrictions of this nature have been adopted in some of the states and a temporary reduction in gross loading during the spring is quite common procedure, but it is often not well enforced.

6. Traffic Volume. *General Data.*—Administrative interest in traffic volume is largely confined to the decision as to whether growth in volume shall be handled by concentration on a few main roads of exceptional width and strength, or by distribution over parallel routes of lower individual carrying capacity. The answer to this question appears to be that distribution of traffic is usually the proper solution. The principle of traffic distribution seems sound, for if a specified volume of traffic is distributed by the use of two roads of moderate width and cost in place of one road of exceptional width and exceptional cost, more territory is reached directly; congestion and danger are reduced and alternate routes are provided during repair periods. The normal growth in the number of improved roads tends to take care of normal traffic growth. That is, at the present stage of highway improvements it is not likely that it is justifiable to build a pavement width of more than 18 to 20′ on single roads; it is probably better to parallel the road for traffic of over 6000 daily (10-hr. count in summer) rather than increase the pavement widths, except for short distances near large cities where an unavoidable concentration of traffic occurs.[1] 3 lane pavements (27′ width) are good up to 7000 to 9000 vehicles (10 hours in summer) and beyond that volume 4 lane (36′ to 40′) are desirable.

[1] Maximum permissible hourly peak load for 2 lane traffic (20 ft. pavements) without dangerous congestion about 1500 vehicles per hour. (Penn. observations 1926.) Making allowance for ratio of peak hour to 10 hour average this checks the text 10 hour limits.

These capacities for different widths assume reasonable driving comfort for average mixed traffic and are based on Western New York experience on rural highways. 15,000 to 20,000 vehicles have passed over a two lane highway in this district in 24 hours but it is dangerous, inconvenient and decidedly unpopular.

Traffic volume fluctuates and gradually increases. Before a road system is completed, there is no definite information on which to base probable future traffic, but it can be approximated fairly closely by a careful study of the district in comparison with other similar districts in which a road system has been completed. Total motor vehicle registration gives some basis for estimating probable volume on the main roads, as while it is not a sure index of the volume of rural travel, it is a very good index of probable

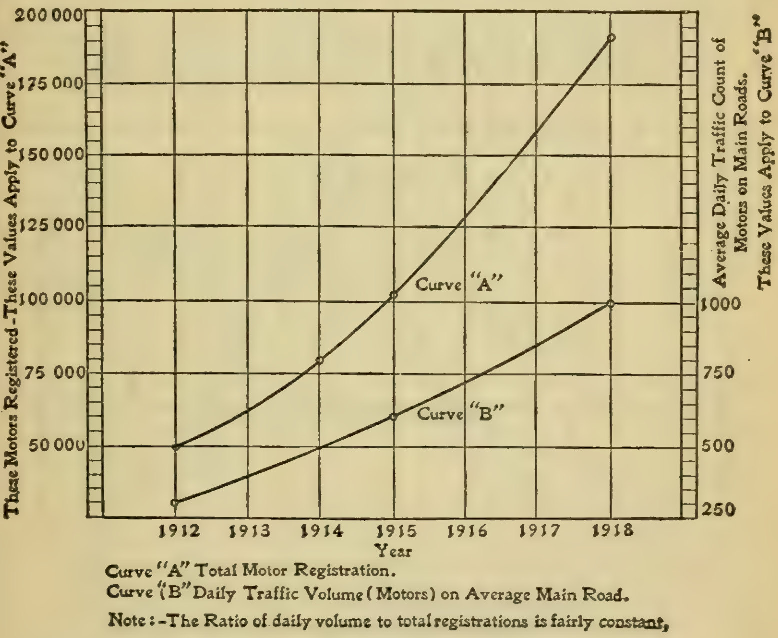


FIG. 5.—Comparison total motor vehicle registration and average rural road traffic volume. (State of Massachusetts.)

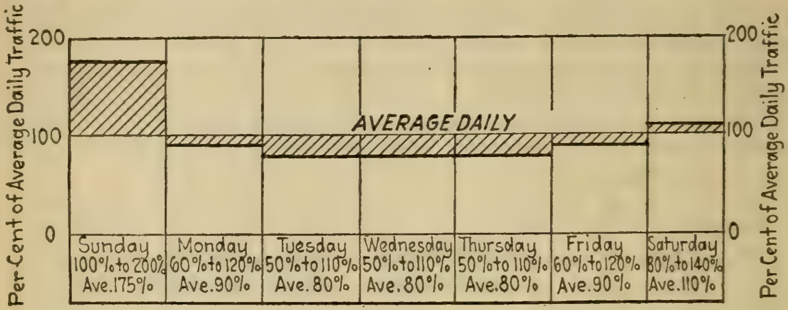
volume (see Fig. 5), although after a certain number of motors per capita is reached the volume of travel on rural roads is not greatly affected except on holidays. During the past 4 years the registration in New York State shows a large increase, but our traffic counts show only a small average increase, particularly on local roads.

Average daily traffic volume on rural roads is not so excessive as commonly believed by the city dweller, who bases his opinion on holiday volume, nor is it likely to continue to increase as rapidly as much of the automobile propaganda would make us think. The growth of motor vehicle traffic on rural highways has been rapid in the past few years, but it cannot be expected to continue at the same rate much longer, for a reasonable limit of the number of cars

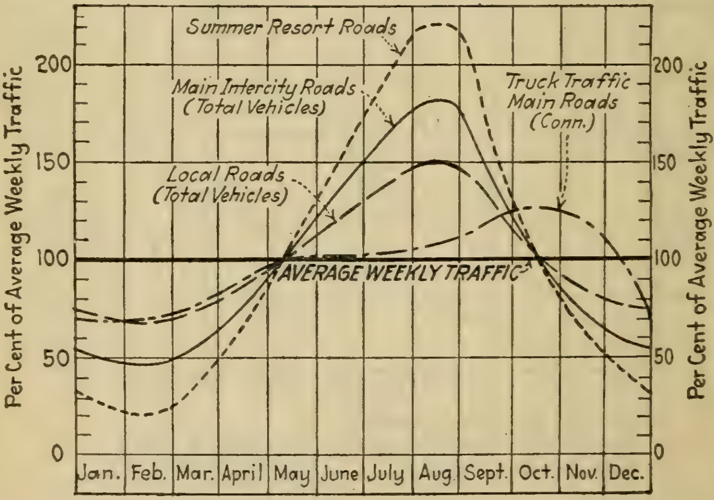
Hourly Fluctuation.—Hourly maximum 150 to 450% of hour average for a full day (24 hr.). Average 300%.

Ratio of Night to Day Traffic (summer months).

Night traffic (7 p.m. to 7 a.m.) ranges from 20 to 60% and averages 35% of day traffic (7 a.m. to 7 p.m.).



Typical daily fluctuation from weekly average (summer months).



Typical weekly fluctuation from yearly average (western N. Y.).

Based on personal records of W. G. Harger supplemented by traffic counts of Connecticut, Maryland, and Pennsylvania (see U. S. Bureau of Roads *Reports* for more complete data).

Diagram B.—Traffic fluctuation.

NOTE.—Individual roads may vary considerably from these curves (agricultural roads generally carry their peak loads in October, etc.), but these data provide some basis for coordinating short-time counts with yearly totals. Considering ratios of night to day traffic and seasonal variations, the author has been in the habit of using the following rough rules for deriving total yearly volumes in Western New York from 12-hr. daylight counts (7 a.m. to 7 p.m.) on Friday and Saturday in August.

Summer-resort roads.......	365 days × 70% of 12-hr. count
Main intercity roads.......	365 days × 80% of 12-hr. count
Local roads................	365 days × 90% of 12-hr. count

FIG. 6.—Typical traffic fluctuation.

which are likely to be operated for any extended mileage on rural highways is being rapidly approached; normal growth can be expected, but at a greatly reduced rate. At the present time not over 2% of the total rural road mileage of New York State carries an average of over 1500 vehicles per day (year-round average), and it is not likely that it is necessary to figure on more than 3 to 5% being subjected to a higher volume than 1500 daily average during this generation.

This indicates that extreme pavement width or the extensive use of very high-grade pavements on a large mileage of road have not much foundation in economic necessity. The effect of a conclusion

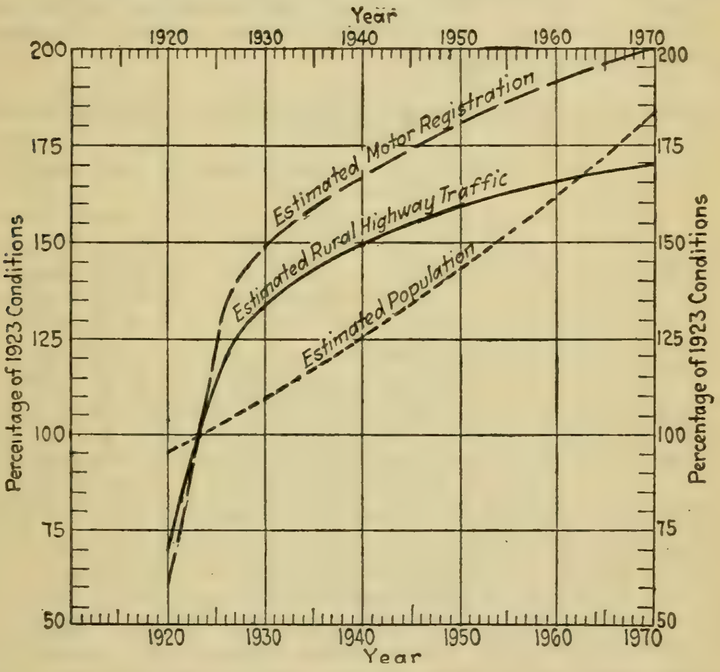


FIG. 7.—Estimated probable average increase in traffic volume. Division No. 4 Western New York.

of this nature is discussed in more detail under Classification (pp. 46 to 48).

Detail Data on Traffic Volume.—Present and future volume of traffic controls engineering design of widths, strength, alignment, and grades and gives the basic data for economic tests of design. For a large mileage of state system roads quite accurate general average laws can be established by careful traffic census counts taken from year to year, which are sufficiently reliable for broad conclusions. Individual roads, however, will vary greatly from the average and any estimates of future volume for detail design purposes must depend on a detailed study of prevailing and probable future volume, depending on adjacent territorial development

modified by the expected improvement of adjacent roads. If this material is carefully analyzed, however, even individual roads can be given a broad general classification which helps materially with a rational and economic design. Examples of such estimates are given on page 33.

The reader is referred to the U. S. Bureau of Public Roads *Bulletins* for the best traffic census data in different parts of the country. In case these data cannot be easily obtained, the following data illustrate typical traffic fluctuation for conditions similar to the northeastern states.

Figure 6 illustrates typical traffic fluctuation (page 30.)

Figure 7 gives the general basis for estimating future traffic in western New York, and the details of its application to specific roads is explained as follows:

ESTIMATING FUTURE TRAFFIC VOLUME (FIG. 7) FOR ECONOMIC ANALYSIS

(From a paper prepared by W. G. Harger for the Michigan A.A.E., February, 1924)

"The kind and volume of future traffic are the fundamental factors of economic analyses, which are only possible where maximum loading and speed of trucks are rigidly controlled. Traffic volume controls the selection of reasonable types of pavement considering first cost, maintenance and renewal; it controls rational limits of expenditure for relocations and grade improvements and sets the value of the improvement from the standpoint of reduction in vehicle operating costs.

"For the original construction design of a new system of modern highways, it is impossible to forecast with exactness probable future traffic volume, but a fair approximation can be derived from a study of similar districts, where the road systems have been completed. As previously stated, economic analyses of highway design become of increasing practical value for reconstruction programs financed by direct vehicle taxation, and for such programs where the system has been completed and traffic routes established very close estimates of present traffic can be obtained by means of careful traffic counts similar to the Connecticut Census now under way, under the direction of the U. S. Bureau of Roads. Future traffic is largely a matter of judgment, but there is every reason to believe that we have enough data to make reasonable forecasts for the purpose of arriving at rational general conclusions. In making such forecasts more liberality is justified in connection with economic analyses of relocations and grade reductions than for pavement construction, as pavements are temporary at best. That is, an allowance for 50 years' growth is perhaps reasonable in connection with relocations grading and bridges and for 15 years' growth in connection with pavement design. The percentage of increase for these periods will, of course, vary for each road, depending largely on how near each locality has reached the saturation point of ton miles or car miles traveled on rural highways, and it is also affected by additional mileage of improved roads to be constructed during these periods which tend to reduce congestion.

"For western New York conditions (one motor per five and one-half people in 1923) the author has been in the habit of estimating average future volume on the basis of 170 % of present traffic (1923) for grading estimates and 150 % for pavement estimates which are modified for each road by the probable effect of the improvement of adjacent highways (see Fig. 7 and examples given beyond). These percentages will be reduced from year to year as the district more nearly reaches the saturation point. The comparatively small difference in the allowance of 50- and 15-year periods is due to the fact that this district is approaching the saturation point, for present population, except on the main roads carrying foreign traffic on which large future increases will be prevented by the construction of parallel routes. Our rural population is not increasing and the ratio of cars per capita for farm population has about reached the saturation point. The increase in population for this district will be due largely to the increase in the size of the city of Rochester. After 1930 the registration curve (Fig. 7) should not show much

increase over the population curve. Up to 1930 there will be considerable increase in the registration curve, but our traffic counts for the last 6 years show that the volume of traffic on rural highways does not keep pace with registration curve.

Examples of Figuring Future Volume

"The relation between short-time counts and average yearly volumes is shown in Fig. 6, based on the Maryland and Connecticut data. This gives an approximate basis for judgment in deriving yearly volumes from short-time counts."

Example 1. *Clover Street Road* 294, *Monroe County.*—"1923 Census (12-hr. count in August) shows 550 vehicles (average mixed traffic). The year-round average daily 24-hr. volume is probably about 90 % of the 12-hr. count. This road will not be affected by additional adjacent improvements, as the system is complete, so an average daily volume of 500 × 170 % = 850 vehicles for grading estimates or 500 × 150 % = 750 vehicles for pavement estimates is estimated. This estimate places this road under Class II traffic.

Example 2. *Pittsford Palmyra Road* 766, *Grade-crossing Elimination Near Pittsford Village.*—"The 1923 Census shows 750 vehicles daily, average for present condition of the system. Within 3 years the Pittsford Victor Road will be completed, which will divert at least 60 % of traffic from Road 493 to Road 766. The 1923 Census on Road 493 shows 1900 daily. No other changes in the system are liable to affect traffic on Road 766. Future volume is, therefore, figured in two parts.

Estimate for Relocations

Normal growth	750 × 170 % =	1275 daily
Diversion growth	(60 % of 1900) × 170 % =	1830 daily
Estimated future total		3105 daily
	Say, 2500 to	3500 daily

"This estimate places this improvement on Class I traffic basis."

Example 3. *Leroy Caledonia Road* 5463, *State Route* 6, *Genesee County.*—"The 1923 Census shows 3400 average daily. Within 2 years the completion of the Rochester-Batavia Road, via Churchville, will divert considerable traffic, and within 10 years the completion of the Avon-Buffalo Road via Alexander, will cause a future diversion of traffic.

"If there were no future diversions, reconstruction design would have to be considered on the basis of 3400 × 170 % = 5800 vehicles daily, which would require a 27′ width of high-type pavement. Considering the diversions, the future traffic will probably not exceed 2500 to 3500 daily average, which can be amply served with either an 18 or 20′ width of rigid pavement; that is, this road remains Class I, but it is not likely to become Class I plus.

"These examples illustrate the value of future estimates for general conclusions and their limitations for hair-splitting analyses of pavement design."

The effect of traffic volume on widths, pavement types, etc., is taken up in detail under Economic Engineering Design (p. 55).

7. Traffic Safety and Convenience.—Causes of accident are shown in Tables 9, 10, 11, and 12. It can be seen that at least 50% of accidents are caused by reckless or careless driving or defects in vehicle equipment, and are not preventable by highway safeguards.

(text continued on page 36.)

TABLE 9.—CAUSES AND LOCATION OF ACCIDENTS
1922 and 1923 accidents in Wisconsin (State Road System)

	1922 and 1923	Per cent of total
Total number of accidents	2,981	
Number of people involved	10,258	
Number of people killed	267	
Number of people seriously injured	794	
Number of people slightly injured	2,506	
Accidents occurring on straight road	2,044	68.6
Accidents occurring at curves and corners	479	16.0
Accidents occurring at railroad crossings	179	6.0
Accidents occurring at crossroads	138	4.7
Accidents occurring on hills	34	1.2
Accidents occurring at miscellaneous places	107	3.6
Accidents due to reckless driving	1,628	54.9
Accidents due to improper or no lights	218	7.2
Accidents due to broken car mechanism	151	5.0
Accidents due to intoxicated drivers	154	5.1
Accidents due to weather conditions	167	5.7
Accidents due to car on wrong side of road	74	2.5
Accidents due to narrow bridges and culverts	53	1.7
Accidents due to miscellaneous causes	536	18.0

TABLE 10.—CAUSE ANALYSIS, STATE OF MASSACHUSETTS
(Fiscal year 1923)

Principal Classes of Circumstances at Time of Accident	Fatal Automobile Accidents
Too fast for conditions	218
Inattention	122
Child darting in front of moving vehicle	75
Pedestrian running across street	47
Intoxicated operator, or had been drinking[1]	46
Pedestrian from front or behind vehicle	33
Wrong side of road	37
Confused operator	32
Defective brakes	30
Inexperience	31
Too close to other vehicles	24
Obstructed view	20

[1] In these 46 liquor cases, 62 persons were killed and 53 injured.

ACCIDENTS ON INDIANA STATE HIGHWAYS

Collisions

	Mar. 1, 1922–Sept. 30, 1922	Oct. 1, 1923–Sept. 30, 1924	Oct. 1, 1923–Sept. 30, 1924	Oct. 1, 1924–Sept. 30, 1925
Total number accidents reported	157	332	370	654
Collision with other machines	49	109	160	302
Collision with railroad trains (steam)	4	16	6	19
Collision with guard rails	5	14	15	17
Collision with bicycles	1	0	0	1
Collision with culvert headwalls	7	9	11	14
Collision with telephone poles	7	21	12	33
Collision with wagons	2	11	6	7
Collision with electric cars	1	6	5	11
Collision with fences	8	12	12	21
Collision with animals	2	7	8	5
Collision with bridges	5	20	30	40
Collision with miscellaneous objects	20	48	14	22
Causes of accidents				
Fast driving	99	140	181	335
Steep grade	8	14	21	28
Sharp curve	41	51	33	78
Lack of guard rail	8	26	21	22
Wet surface	3	13	16	28
Deep ditch	5	15	13	27
Intoxication	23	25	40	66
Glaring headlights	9	17	25	54
Narrow roadway	29	59	41	45
Obstructed view	9	29	24	47
Miscellaneous causes	25	37	14	37
Deaths and injuries from these accidents were reported as follows:				
Accidents reported	157	332	370	654
Deaths	30	38	50	103
Injuries	133	196	255	529

TABLE 11.—STATE OF CONNECTICUT, JAN. 1–AUG. 15, 1924

Cause	Number	Per cent distribution
Recklessness of motorist	5,929	57.8
Carelessness of child pedestrian	382	3.7
Carelessness of adult pedestrian	777	7.6
Carelessness of contributor	1,083	10.6
Equipment	537	5.2
Miscellaneous	180	1.7
Minor accidents	1,376	13.4
Total	10,264	100.0

TABLE 12.—FATAL-ACCIDENT SUMMARIES FROM NATIONAL AUTOMOBILE CHAMBER OF COMMERCE

Totals reported for seven months, 1924	
Total motor fatalities reported	1390
Collisions between motor vehicles	248
Motor vehicles *vs.* electric railway	126
Motor vehicle at railroad crossing	91
Motor vehicle overturning	57
Motor vehicle striking stationary object	44
Causes of Fatalities	
A. Where fault of motorist was a major factor:	
Speeding	211
Violating rules of road	141
Inattention	35
Inexperience	51
Confusion	36
Intoxication	62
Total	536
B. Where physical conditions were major factors:	
Fog, snow, or rain	86
Skidding	73
Defect in vehicle	64
Too strong lights on vehicle	20
Poor street lighting	8
Defect in road	27
Confusion in dimming	13
Total	291
C. Where fault of pedestrian was a major factor:	
Adult jaywalking[1]	375
Children coasting in street	24
Pedestrians confused	71
Children crossing in middle or playing in streets[1]	224
Intoxication	13
Physical disability	20
Children stealing rides	00
Total	727

[1] The National Automobile Chamber of Commerce notes that, while these cases are technically the fault of pedestrians, yet the motorist must be ever alert to unexpected traffic violations of those on foot. Safety, alertness, and courtesy, rather than insistence on right of way, should be the motorist's rule.

Preventable accidents can be reduced by means of warning of dangerous physical conditions which have not yet been made safe and by means of safe highway construction, considering ample width, easy curves, easy grades, non-skid pavement surfaces, clear view, railroad-crossing protection, night illumination, and the segregation of pedestrian and motor traffic.

The amount of money that it is desirable to spend on safeguards is largely controlled by the volume of traffic. Extreme danger should be avoided on any improved road, but on the lighter-traveled roads considerable must be left to the care of the driver. On such roads about all that is justified are danger signs and cheap guard rails that warn instead of actually protecting, and on many mountain roads even cheap guard rail is out of the question. On heavy-travel special-service roads, all possible safeguards should be employed, such as the elimination of railroad grade crossings, substantial strong concrete guard rail or retaining walls, widening and banking of pavement on curves, pavement center-line traffic marking, a safe "sight distance" ahead at all times, hard well-kept shoulders, shallow ditches, warning and guide signs for the direction of travel, sidewalks for pedestrians, and night illumination. Safety policy is summarized as follows: On light-traffic roads confine safety provisions to warnings. On heavy-traffic routes spend all the money that is necessary to make the road as nearly foolproof as possible.

The details and cost of these safety devices are discussed under the detail design data for the various items involved.

Speed of Traffic.—Permissible and desirable speed of traffic is considered from the standpoints of safety, driver's preference, road-carrying capacity, and time of travel on through routes between populous termini. Permissible speed is a matter of dispute between even the best authorities in highway work, but there are certain well-established fundamentals. Safe speeds depend on type, weight, and condition of the road vehicle, expertness of vehicle operator, highway alignment, grade, pavement width, type of surface, and spacing of vehicles (congestion), and will vary from 10 to 40 m.p.h. From the standpoint of safety alone it is well established that, for any given existing highway condition, increased speed increases danger. At points where a low speed is required for safety, highway improvements can generally be made which permit reasonable increase in speed with practically no increase in danger, but such improvements are often very expensive and it is necessary to arrive at reasonable limits of speed which will be used as a basis for design.

It is self-evident that road users desire high speed and are exhilarated by "stepping on the gas," but it is also evident that this tendency is the cause of most accidents; that long, straight, smooth, and wide highways encourage high speeds, which are productive of a large number of accidents under what appear to be safe driving conditions, and that it is hardly justifiable to spend large sums of money to encourage excessive speed. From the standpoint of reasonable safety and reasonable desire for speed, designs which are safe for 25 m.p.h. on curves in rough country and 35 m.p.h. for average driving conditions in ordinary topography should serve satisfactorily for main roads subject to mixed traffic. These limits can be reduced for the less used roads.

Maximum road-carrying capacity depends on speed and the necessary spacing between vehicles moving at different rates of speed. From the standpoint of road-carrying capacity recent

studies (1925) have shown that the greatest number of cars can be carried past a set point when the average speed of travel is about 22 m.p.h. and that the tonnage capacity of the road is reduced by either increasing or decreasing this speed limit. The accompanying table shows the effect of speed on road capacity. Data of this kind are, of course, only useful for police regulation of congested roads.[1]

Speed of travel, m.p.h.	Capacity of road in percentage of maximum
15	90
20	100
25	100
30	95
35	90
40	80

From the standpoint of reduction in time of travel between cities, some Engineers now advocate designs permitting 50-mile speeds, but such speed requires so-called super highway design, which eliminates grade crossing of intersecting roads, requires extremely high standards of alignment grade and pavement width, and limits the road solely to the use of high-powered cars making the through run. There are very few conditions where such special highways are necessary or economically justified at the present time (1926).

The following quotation from James E. Kelly discusses safe city and rural speeds:

"I believe that an average speed of more than 15 m.p.h. is unsafe where blocks are 0.1 mile or shorter and intersections obscure. Where blocks are 0.3 mile or more long this can be increased to 20 miles with safety if there is very little parking. Parked cars along streets, obscure driveways, and pedestrians, particularly children playing on streets, are the greatest menace to safety and hence retard traffic.

"In the open country with long straight stretches of highway, well-banked curves of long radii and clear view, 40 to 45 m.p.h. is safe for an experienced driver with a well-built carefully maintained car. A speed greater than 45 m.p.h. generally brings grief to someone, usually the driver."

8. Traffic Range.—Available data indicate that probably 70 to 95% of road traffic can be classed as local service; that is, it has its origin and finish within a comparatively short distance, say 30 to 40 miles, and consists of hauling garden truck to cities or produce to shipping points, ordinary business intercourse, and short pleasure trips. The other 5 to 30% may be classed as long-distance traffic, consisting of pleasure touring, commercial travelers' cars, and trucking between cities. These ratios of general traffic do not, of course, apply to any one road and may be actually reversed on certain special touring roads, but they probably apply to road systems as a whole for most counties and states and indicate the general administrative principle that local traffic is entitled to first consideration in the location of roads and their design, except for a comparatively small mileage of special-service highways.

[1] For normal capacity two lane highways see page 28.

The statistics compiled by the National Automobile Chamber of Commerce for 1920 show that 30% of all automobiles and trucks are owned by farmers; that 60% of all motors are registered from towns of 5000 inhabitants or less and the rural districts. This is a very conservative basis for deriving the minimum volume of traffic originating on or using side roads. The general city public and even engineers are inclined to think too much of the main roads in connection with any state or national program of highway improvement. This is natural, as the main roads are more spectacular; they probaby carry 90% of the traffic during some part of the journey. A system of improved main roads gives quite complete service to intercity travel; it gives quite complete service to tourist travel, but it gives only partial service to local travel, and local traffic is a very large proportion of the total travel on our roads. A large percentage of traffic either originates on or uses a side road during some part of its journey; that is, the main roads only provide direct contact service to about 10 to 20% of the producing area of the district, and this element of direct contact is a fundamental service of roads. It is, therefore, extremely poor policy to overemphasize the importance of the main roads to the extent of disregarding a reasonable treatment of the secondary roads. Main roads are entitled to first consideration and better construction than the local roads, but they are not entitled to needlessly expensive construction which tends to delay too long a reasonable treatment of the system as a whole. The general character of the system must progress as rapidly as possible up to the standard of general utility; beyond that standard there is no harm in concentrating exceptional expenditures on special roads. The difference in volume of traffic on the local and main roads calls for a wide variation in suitable pavement design. The administrative problem considers the general suitability of pavement types under different classes and volume of traffic.

Trip Mileage of Passenger Cars Used for Business and Non-business Purposes[1]

Trip mileage	All passenger cars, %	Business cars, %	Non-business cars, %
0–19	55.7	65.3	48.0
20–39	16.3	14.4	17.9
40–59	9.2	8.2	10.1
60–79	5.0	3.9	5.9
80–99	3.6	1.7	5.1
100–149	4.3	3.3	5.1
150–199	1.7	1.2	2.1
200–299	2.7	1.5	3.7
300–399	0.5	0.2	0.7
400–499	0.2	0.1	0.4
500 and over	0.8	0.2	1.0
Total	100.0	100.0	100.0

[1] Connecticut Traffic Census, Public Roads, August, 1926.

Percentages of All Passenger Cars Used for Business and Non-business Purposes, Classified According to Trip Mileage

Trip mileage	Business cars, %	Non-business cars, %
0–19	52.2	47.8
20–39	39.3	60.7
40–59	39.4	60.6
60–79	34.8	65.2
80–99	21.6	78.4
100–149	34.5	65.5
150–199	30.9	69.1
200–299	24.6	75.4
300–399	17.6	82.4
400–499	17.2	82.8
500 and over	12.6	87.4
Total	44.5	55.5

Distribution of Net Tonnage of Commodities Transported by Motor Truck over the Connecticut State Highway System by Length of Haul

Length of haul, miles	Proportion of total net tonnage, %	Length of haul, miles	Proportion of total net tonnage, %
0–9	36.3	70–79	2.6
10–19	19.2	80–89	0.8
20–29	11.6	90–99	1.0
30–39	9.1	100 and over	8.6
40–49	4.0		
50–59	4.6	Total	100.0
60–69	2.2		

9. General Suitability of Types.—It is not necessary to go into the details of the minor advantages of various standard pavements; these will be discussed under the general principles of Engineering Selection (p. 58). Administrative action, however, properly considers the fundamental desirability of general types, their relative cost (both initial and final), and their natural rate of depreciation as far as they affect methods of taxation, terms of bond issues, and maximum tax rates.

Two general classes of pavement are considered suitable for modern highways: rigid and flexible. The distinctive feature of the rigid type is a non-elastic concrete base which distributes the concentrated traffic wheel loads over a safe area of the natural subsoil by slab action. All sorts of surfacing are used (sheet asphalt, brick, stone block, asphalt block, or exceptionally strong concrete). The distinctive feature of the flexible type is a base course constructed of some form of macadam, gravel, field stone, or Telford, distributing the wheel loads over a safe area of the natural

subsoil by means of the depth of the course and the mechanical interlocking or friction of the integral fragments of the material. This type has all sorts of surfacings, the most common surface being some form of modern macadam, but under certain conditions it is proper to use sheet asphalt or similar surfacings and almost any type of block, provided the joint filler is flexible to permit slight settlement without rupture. Rigid pavements are desirable for heavy traffic. The flexible pavements are desirable for moderate and light traffic.

The advantages and disadvantages are as follows: Rigid pavements are destroyed by the action of the elements as well as by traffic. They crack due to the settlement of new fills or frost heave; they shatter due to changes in temperature; they disintegrate due to vibratory fatigue and frost action. They are comparatively difficult to repair and prohibitive in cost except for rich communities. They, however, handle heavy auto trucking more satisfactorily than macadam construction. They need comparatively little surface maintenance for the first few years, and for this reason traffic is inconvenienced less than on macadams; they last a longer period without reconstruction than macadam pavements, and traffic is therefore interrupted less; they bridge over small areas of weakness in the subgrade, such as culvert backfills, etc., better than macadams. There is no question but that they are desirable on roads carrying a large amount of heavy-truck traffic.

For moderate traffic requirements, however, the flexible type of pavement is probably more suitable. It complies better with the usual conditions. It generally costs less to construct; is not seriously damaged by settlement of new grading or frost heave; can be easily and cheaply repaired; can be strengthened gradually by the addition of stone to meet practically any loading; and when a solid foundation has been accomplished can be recapped with a higher-grade surface, which rids it of the continuous-maintenance draw back.

It is well to bear in mind that the quality of rigidity is not inherently desirable, considering the fact that the earth foundation is always susceptible to heave and settlement and that this will occur to some extent no matter what precautions are taken. Rigid design should be resorted to only when the desired result can be accomplished more cheaply by this means than by the flexible form of construction; this occurs under exceptionally heavy-unit traffic. The fact that rigid pavements, in general, include a higher type of surfacing than macadam constructions leaves the impression in the popular mind that such a surface is a result of rigidity, while, as a matter of fact, there is sufficient data to state with reasonable assurance that, unless the pavement is subjected to an unusually large volume of heavy-unit motor trucks, a first-class macadam, field stone, or Telford base is often superior to concrete base for asphalt or small block surfacings on account of the reduction in frequency of temperature cracks.

The present rather extreme tendency favoring rigid construction under moderate traffic is based largely on the record of failures of

(text continued on page 46.)

TOTAL MILES OF ROADS IN U. S. AT END OF 1924—(STATE, COUNTY AND LOCAL ROADS COMBINED)
Compiled from Bureau of Public Roads Statistics and State Reports, by Portland Cement Association

States	Grand total mileage	Unimproved and earth partially graded	Earth to established grade and drained	Total miles of road surfaced	Low type		Medium type	
					Sand-clay	Gravel, etc. untreated	Water-bound macadam untreated	Surface treated macadam and gravel
Alabama	61,491.2	48,833.4	157.8	12,500.0	7,075.1	4,186.0	698.9	240.2
Arizona	22,355.3	17,055.7	2,238.3	3,061.3	648.3	1,906.6		
Arkansas	74,865.0	66,220.5	2,806.0	5,838.5	150.2	4,499.9	345.2	76.4
California	75,618.0	30,117.8	30,238.0	15,262.2	....	6,873.0	1,005.4	566.0
Colorado	67,620.5	25,867.3	33,003.3	8,749.9	....	8,550.0		
Connecticut	12,219.6	7,277.9	2,530.0	2,411.7	....	83.5	111.5	1,501.8
Delaware	4,410.8	1,923.5	1,790.0	697.3	....	50.0	30.0	153.5
Florida	28,413.5	19,369.9	44.7	8,998.9	3,171.5	1,505.6	679.4	1,291.8
Georgia	98,364.6	52,978.6	26,198.8	19,187.2	14,128.4	3,553.8	219.6	140.7
Idaho	34,816.3	11,217.9	12,630.0	10,968.4	68.2	10,342.5	325.0	
Illinois	96,328.1	80,437.4	1,717.8	14,172.9	....	6,783.0	2,623.1	138.0
Indiana	80,533.7	40,514.3	130.7	39,888.7	....	25,461.1	12,028.6	238.0
Iowa	104,624.2	97,134.7	2,762.0	4,727.5	....	4,223.2		
Kansas	129,125.0	127,395.4	319.8	1,409.8	65.0	430.1	240.0	63.0
Kentucky	68,704.0	50,950.0	687.4	17,065.7	70.0	3,698.1	11,125.5	1,615.3
Louisiana	39,803.0	35,125.0	....	4,678.0	....	4,521.6	....	87.1

Maine	20,939.8	16,966.6	8.9	3,964.3	8.2	2,756.8	605.4	347.6
Maryland	14,151.8	8,722.0	1,807.0	4,357.2	414.0	1,168.1	189.0	1,419.2
Massachusetts	19,098.4	11,775.4	12.8	7,310.2	2.7	3,126.5	96.2	2,019.3
Michigan	77,284.1	54,751.1	1,534.8	20,998.2	78.0	16,208.0	1,254.0	1,035.4
Minnesota	107,827.0	81,650.4	3,866.4	22,310.2	3,967.3	17,523.7	83.4	67.4
Mississippi	58,880.4	48,647.9	991.6	9,240.9	366.8	8,193.3	100.2	69.4
Missouri	112,101.1	99,505.2	3,060.2	9,535.7	1,755.3	5,577.0	1,213.8	56.0
Montana	64,176.9	62,966.6	280.1	930.2	....	889.7	....	0.6
Nebraska	87,391.8	82,999.7	3,251.2	1,140.9	386.5	676.4	0.7	
Nevada	22,778.8	20,178.6	1,695.2	905.0	....	823.6	0.5	10.2
New Hampshire	13,089.0	11,852.2	10.4	1,226.4	....	322.9	9.7	728.4
New Jersey	17,716.2	74.9	10,193.2	7,448.1	....	2,838.5	1,342.4	739.1
New Mexico	47,030.7	43,939.1	680.7	2,410.9	731.0	1,615.8		
New York	81,873.0	56,886.3	447.4	24,539.3	....	5,229.8	3,484.4	6,036.5
North Carolina	67,906.7	48,867.4	889.6	18,149.7	12,515.7	3,291.9	400.3	119.8
North Dakota	106,498.4	103,899.5	1,544.0	1,054.9	....	1,050.1		
Ohio	84,532.1	50,667.5	283.8	33,580.8	501.0	13,748.5	13,113.8	951.8
Oklahoma	134,262.0	128,975.3	3,618.7	1,668.0	....	885.5	29.7	267.8
Oregon	49,770.0	32,264.0	7,386.0	10,120.0	....	8,786.0		
Pennsylvania	92,020.5	72,007.7	3,913.6	16,099.2	0.5	665.3	696.2	2,746.8
Rhode Island	2,320.6	1,491.1	178.0	651.5	....	60.5	47.8	198.0
South Carolina	64,408.5	48,038.7	7,288.9	9,080.9	8,126.9	588.7	33.9	18.5
South Dakota	115,805.4	109,803.7	3,987.7	2,014.0	....	2,012.8		
Tennessee	64,726.7	41,538.1	10,855.6	12,333.0	....	5,597.4	4,865.8	830.8
Texas	167,685.0	145,791.1	2,845.0	19,048.9	2,109.1	13,958.3	571.2	1,419.2
Utah	23,381.1	18,437.9	1,989.6	2,953.6	697.6	1,920.6	12.0	3.6
Vermont	14,861.0	9,825.6	554.0	4,481.4	....	4,341.8	9.0	75.8
Virginia	62,106.4	51,563.0	2,202.2	8,341.2	2,528.8	1,744.2	762.4	1,487.2
Washington	48,883.7	22,799.3	9,559.2	16,525.2	....	14,205.9		
West Virginia	35,565.8	32,993.0	937.7	1,599.1	....	173.4	231.1	47.7
Wisconsin	78,964.2	20,456.3	34,070.7	24,437.2	4,115.8	16,915.9	1,389.7	
Wyoming	46,319.2	45,071.8	523.2	724.2	....	683.8	....	2.2
Totals	3,003,649.1	2,297,827.2	237,758.0	468,798.3	63,681.9	244,248.7	59,974.8	26,810.1

TOTAL MILES OF ROADS IN U. S. AT END OF 1924—(STATE, COUNTY AND LOCAL ROADS COMBINED)—*Continued*

Compiled from Bureau of Public Roads Statistics and State Reports by Portland Cement Association

States	Medium type		High type						
	Bituminous macadam by penetration	Misc.	Sheet asphalt	Bituminous concrete	Cement concrete	Block pavements			
						Brick	Asphalt	Wood	Stone
Alabama	152.4	....	24.9	104.8	17.5	....	....	0.2	
Arizona	....	....	15.0	91.4	400.0				
Arkansas	246.7	....	41.4	296.9	181.8				
California	1,370.6	900.0	....	1,087.9	3,459.3				
Colorado	....	....	....	....	199.9				
Connecticut	280.8	....	4.0	143.9	284.5	1.7			
Delaware	39.6	....	....	20.5	396.8	6.9			
Florida	334.2	....	785.2	64.7	257.3	764.2	145.0		
Georgia	347.7	....	55.3	82.2	658.9	0.6			
Idaho	....	70.0	5.4	116.2	41.1	....	.....	.....	.....
Illinois	67.8	....	33.0	56.0	4,232.0	232.0	....	8.0	
Indiana	396.3	....	....	172.0	1,370.9	221.3	....	0.5	
Iowa	....	....	....	....	450.4	53.9			
Kansas	72.9	....	....	....	426.5	112.3			
Kentucky	228.1	97.0	56.0	13.8	147.7	9.2	....	5.0	
Louisiana	23.4	....	....	18.0	9.9	18.0			

Maine	183.6	...	3.8	1.5	57.4				
Maryland	70.0	189.0	56.0	28.2	816.0	7.7			
Massachusetts	1,557.9	...	...	318.2	186.7	0.8	...	0.1	1.8
Michigan	201.0	231.9	2.0	280.0	1,694.1	13.8			
Minnesota	10.6	...	8.5	88.1	535.5	13.2	...	12.5	
Mississippi	232.9	...	6.7	19.8	232.6	19.2			
Missouri	159.9	...	1.0	5.6	757.1	10.0			
Montana	5.5	...	...	2.3	32.1				
Nebraska	...	...	2.6	10.2	45.0	19.5			
Nevada	24.0	...	...	1.6	45.1				
New Hampshire	98.2	...	...	59.2	8.0				
New Jersey	725.8	...	291.4	706.8	664.2	40.9	3.1	6.3	89.6
New Mexico	...	...	...	0.7	63.4				
New York	6,489.2	...	16.5	215.9	2,709.8	329.5	23.4	0.6	3.7
North Carolina	186.6	0.5	12.0	802.3	754.0	66.1			0.5
North Dakota	...	...	...	...	4.8				
Ohio	1,638.7	414.7	44.5	218.3	1,428.3	1,521.2			
Oklahoma	...	...	...	80.0	385.0	20.0			
Oregon	...	130.0	...	919.5	284.5				
Pennsylvania	349.4	7,796.3	207.3	603.3	2,471.6	548.3	6.1	3.4	4.7
Rhode Island	160.9	...	8.9	141.9	30.5	...	...	...	3.0
South Carolina	16.8		66.3	67.8	162.0				
South Dakota	...	...	...	...	1.2				
Tennessee	487.9	...	363.2	67.9	119.0	...	...	1.0	
Texas	357.5	...	106.4	112.0	372.8	42.4			
Utah	7.2	...	10.5	59.1	243.0				
Vermont	22.9	...	...	...	31.9				
Virginia	583.1	770.5	10.7	7.6	445.8	0.9			
Washington	151.6	160.0	21.8	266.3	1,657.3	62.3			
West Virginia	421.4	24.2	0.7	75.7	426.9	198.0			
Wisconsin	...	...	...	94.6	1,921.2				
Wyoming	...	...	...	27.1	11.1				
Totals	17,703.1	10,784.1	2,261.0	7,549.8	31,132.4	4,333.9	117.6	37.6	103.3

old, thin, inadequately designed and maintained macadam roads. Very few of the more recent, carefully designed macadams have been unsatisfactory under a traffic of less than 2000 vehicles daily. A small percentage of all types of pavement fails either on account of poor design, poor construction, or poor maintenance, but there is no such thing as type failure if moderately good judgment is used in the design and maintenance. Road failures are personal human failures.

Considering that road improvements are generally handicapped by a shortage of funds, that, of necessity, they must advance by successive stages, that the flexible types are usually the cheapest in first cost, that they are also economical in the long run for a moderate volume of traffic, and that the surface maintenance problem can be minimized by using various types of surface, it is generally good policy to give these types the preference for the first stages of improvement programs; even for the final stages they are the best investment for the community for probably 90 to 95% of the total road mileage in most districts.

To illustrate this more definitely, the following extract is quoted from the report on the Monroe County system (New York State)

"We advocate the original construction of crossroads of thick modern water-bound macadam utilizing local materials as much as possible and maintained by surface oiling.

"We advocate the original construction of our secondary radial roads, of penetration, bituminous macadam, utilizing local materials to their fullest reasonable extent and maintained by surface oiling.

"We advocate the construction of our main trunk-line heavy-hauling roads of rigid pavements, using the best materials that can be obtained, but varying the type to secure, in each case, the cheapest first-cost pavement always considering the possible use of local materials proper for the type of road in question. For these roads we have no choice between cement concrete, brick, sheet asphalt, asphalt block, or stone block on concrete bases.

"We advocate the gradual resurfacing of the heavier-traffic macadam roads with Topeka mix, small brick cubes, etc. We have successfully utilized this method in reducing high surface-maintenance costs where the macadam foundation was solid enough for the traffic, and have adopted this method for a number of our roads. We have examples which have stood a 10-years test successfully.

"We believe that the community has been better served by constructing 10 miles of macadam in place of a possible 6 miles of rigid pavement.

"We believe that the county has been better served in the past and will be best served in the future by variable road designs using for the majority of the mileage modern macadam for the original construction, later modified, if necessary, for a very limited mileage by recapping with a lower-maintenance-cost surface. We advocate rigid pavements eventually for approximately 10% of the total mileage of our roads and for approximately 35% of our state system."

10. Classification of Roads.—In order to strengthen the general discussion, it is, perhaps, just as well to indicate a little more definitely at this point the initial and final cost of roads under different classes of traffic and what types of pavement appear to be best suited for different volumes of travel.

Four general classes of highway can be considered:

Class I Roads.—These roads are usually located along natural transportation routes between large cities located at intervals of less than 100 miles. They may also occur as main radial roads out of cities of, say, 50,000 population and upwards for distances of

5 to 40 miles or as special industrial roads or village streets carrying the concentrated traffic of a large area. These roads generally constitute from 0 to 10% of the total road mileage of the district. They usually carry 2000 or more vehicles per day (10-hr. count in summer). They should have pavements designed to support the traffic of the heaviest commercial trucks permitted by law and should have a pavement width of at least 18 and preferably 20′.

The types most suitable and economical in the long run, from the standpoint of even general utility, are any standard brick or bituminous concrete surface on cement concrete bases, or reinforced cement concrete pavements. Such roads cost today (1926) for the original construction, including grading, drainage, pavements, and incidentals, from $40,000 to $70,000 per mile. The yearly burden to the community, considering interest on first-cost investment plus yearly maintenance plus the yearly allowance for renewing pavement when worn out, amounts to 7 to 10% of the first cost of the road.[1] It seems reasonable for the community at large to assume the burden of original construction plus interest on first cost, and for vehicles to assume the burden of yearly maintenance and the renewal of worn-out pavement. The actual yearly maintenance and renewal charge for these roads are at first small and gradually increase, eventually reaching 3 to 5% of the first cost of the improvement and from there on stay practically constant. This is due to the fact that new pavements require a comparatively small yearly maintenance, which gradually increases until their renewal is necessary. The cost of renewal is high, and when any system of highways becomes old enough (15 to 25 years for this class of road), there will be a constant yearly renewal charge plus a constant yearly maintenance charge, which may easily amount to $2000 to $2500 per mile per year average (1926 scale of costs) for this class of road.

Class II Roads.—These roads are usually main automobile routes at greater distances from the cities than are Class I roads. They have a large touring-car traffic, medium-heavy farm traffic, and some heavy trucking. A Class II road generally carries from 800 to 2000 vehicles per day (10-hr. count in summer). They constitute approximately 0 to 20% of the total road mileage, depending on the general character of the district. They should be designed to handle such traffic, and require a pavement width of 15 to 18′ supplemented by stone or gravel shoulders.

The type of pavement generally most economical for these roads, considering final cost and immediate traffic service, is thick modern bituminous macadam, or if the volume of traffic is close to the 2000 limit, it is possible that reinforced cement concrete may be desirable under advantageous conditions of material supply.

Such roads cost today (1926) from $25,000 to $40,000 per mile to construct and the total yearly burden amounts to about one-tenth of the original cost of construction.

The yearly maintenance and renewal charge for such roads will eventually (in 10 to 15 years) amount to approximately $1500 to

[1] See Chap. VII.

$2000 per mile (1926 scale of costs). For this class of roads this i properly a direct traffic charge.

Class III Roads.—These roads are usually secondary feeder o crossroads in well-settled districts or main roads in sparsely settle districts. They generally carry 300 to 800 vehicles daily (10-hı count in summer). They constitute 5 to 30% of the total mileage They may well be designed to handle at least a 2½-ton truck fo all-the-year service and permit the use of 5-ton trucks in the dr season. They require a pavement width of 12 to 16′. The type of pavement generally most suitable for general utility are thick modern, water-bound macadam with a surface application of oi gravel oiled, or, if the travel approximates the 800 limit, th bituminous-macadam type can be considered.

These roads cost from $10,000 to $25,000 per mile to construc and the total yearly burden approximates one-tenth of the origina cost. The yearly maintenance and renewal charge may amoun eventually in 8 to 15 years to approximately $1000 to $1500 pe mile per year (1926 scale of costs). For this class of road it i proper to charge this directly to traffic.

Class IV Roads.—These roads constitute the purely local servic roads carrying a volume of traffic of less than 300 vehicles daily They constitute 70 to 95% of the total road mileage. They ma well be designed for the all-year-round use of 2½-ton trucks. The do not require much refinement in grading design or in the width c hard surface. A width of 8 to 12′ is sufficient.

The most suitable type is gravel or water-bound macadam Earth or sand clay can be used as a temporary makeshift, but i northern climates they can only be considered as temporary exped ents, as any type of surface not usable the year round for at leas 2½-ton trucks is not a general-utility road.

Class IV roads cost $2500 to $10,000 per mile (1920) and th total yearly burden is about one-tenth of the original cost of con struction. For this class of road it is probable that the communit at large should assume the entire burden of construction, interest maintenance, and renewal, which means eventually for the item of maintenance and renewal alone about $300 per mile per yea (1926 scale of costs); this figure is reached gradually and becomes fairly stable burden in 5 to 10 years after the roads are constructed

11. Importance of Maintenance.—Effective maintenance is th best possible road investment the community can make. I increases the life and lowers the final cost of the improved roads It decreases the cost of traffic operation and inc eases the comfor of travel. It speeds up the general effectiveness of a road systen that is being gradually improved by construction or reconstruction This last is the keynote policy for the poorer districts and is of vita importance to a large part of the country at present. For the poore districts traffic service can be bettered at once, first, by systemati maintenance of all the existing roads; this does not solve the prob lem by any means, but it keeps it from getting worse; second, by the immediate construction of a large mileage of gravel or simila constructions on secondary roads suitable for moderate loads (up to 2½-ton truck and eliminating the large truck for year-round use,

and giving these roads systematic maintenance. This solves the problem up to the standards of general-utility traffic for agricultural districts. It does not solve the heavy-traffic problem, but it helps and is better than waiting indefinitely for the completion of a system of boulevards. Third, the construction of thick modern macadam systematically maintained for the main roads and strong, expensive, rigid pavements systematically maintained for the main commercial hauling routes aggregating a comparatively small percentage of the total mileage. These roads meet heavy-travel requirements.

Fairly good immediate service for traffic is possible only with effective maintenance. It is both physically and financially impossible to solve the problem of improvement of traffic conditions over a large mileage solely by immediate reconstruction of the roads. Maintenance is not entirely eliminated no matter what type of road is built. Fairly efficient maintenance has been accomplished in many cases and is poor in others, but the fact that it can be achieved, provided enough attention is concentrated on it, means that it is possible to get somewhere with a serviceable road program in a reasonable time.

To illustrate the result of a lack of a temporary service program, New York State may be cited. This state has been improving its main roads by state and county aid for 20 to 25 years; the system is still incomplete in many cases. New York's construction program has been excellent; its maintenance of the roads after improvement has been fairly good for some years past, but very little has been done to better the condition of the existing roads at gaps in the improvement; that is, for the past 10 or 15 years, short gaps and detours in stretches of modern roads have caused needless inconvenience to the traveling public. Under the New York road program, the state does not assume the direct responsibility for the condition of the roads on the proposed system until they have been improved by state construction. As soon as a road is adopted as part of the system, the town in which it is located loses all interest in it and does nothing to keep it in condition, although it is supposed to keep it in shape until it is improved by the state. These gaps do not require large expenditures, but the conditions can at present be very materially bettered by comparatively small expenditures on temporary repair and maintenance. All travelers curse these gaps and are more than willing to have their license fee raised slightly to eliminate temporarily the worst features of such roads. It is probable that an extra charge between $1 and $2 per vehicle license per year applied to such work under direct state supervision would result in a tremendous improvement of the few gaps remaining in this particular state (1921).

12. Departmental Organization.—The success of a highway program really depends more on the individual character and professional ability of the men making up the organization than on any other feature; if the men are high grade, nothing radically wrong is likely to develop, and the designs are usually economical. If the men are inexperienced or second rate, no system of standardization or rigid red-tape procedure will prevent wasteful design and poor construction work. It is difficult to retain high-grade men in the

public service, as usually the salaries are niggardly and the advancement slow and often not based on personal ability. One of the foremost state highway engineers resigned in 1920 from his position on the ground that it was impossible to develop an organization which could expend the state highway appropriations in a really efficient manner; that the trouble lay in low pay and the difficulty of advancing the best men; that, while they had succeeded in employing and training some very excellent talent, it was impossible to hold a reasonable proportion of the men and that the turnover was high.

This action expressed in a very effective way the quite universal handicap of a highway executive. Under the existing conditions, the solution most often adopted lies in retaining a few high-grade men as active subordinate assistants to politically appointed heads and rigidly standardizing detail procedure, utilizing quite low-pay men for the actual design and construction end of the program. Such a system produces a moderately good type of highway, as may be seen by observing the results to date, but any engineer actually acquainted with the working of this system will say that the cost of construction is needlessly high in most cases and that the community pays a tremendous amount of money every year because it has not sense enough to adopt a more liberal policy of salary and reward. High-grade engineering pays for itself in actual construction money saving 10 times over the additional salary cost, but this fact is not generally recognized by the public and, while road officials understand it, they either find it difficult to override public sentiment or actually prefer mediocre talent on account of the greater freedom which they have to carry out their own pet schemes. Until the entire organization from inspectors up to the chief is raised to a good standard of individual ability, waste is bound to occur.

Executives have said that they knew moderate-priced roads well designed, constructed, and maintained would serve satisfactorily, but that such results were hard to obtain under existing organization conditions and that in self-defense they considered it good policy to design a rigidly standardized $40,000 a mile highway even on comparatively unimportant Class III roads to get $20,000 worth of service. This expresses in an extreme way the continual waste that is more or less the result of niggardly public service employment policy.

Nothing takes the place of the individual judgment of the rank-and-file men of the organization. What most organizations need are high-grade detail designers and constructors who are encouraged to use their experience and judgment and who are not tied down too much by rigid standardization or their work crippled by demands for plans at such short notice that reasonable care and study cannot be given to each road. This statement must not be construed as an argument for unrelated work by a crowd of individualists, but departmental heads may well rid themselves of the idea that all wisdom originates at the official top and that standardization will take the place of brains.

Even with enough good men in the force it is necessary to have a definite organization plan which defines the duties and responsi-

bility of each man. Too often the organizations are based on overlapping duties, indefinite responsibility, and conflicting authority, and it may be regretfully said that this is often purposely done to make it easier to "pass the buck." (See p. 1271 for definite statement of duties and responsibility of the construction engineering force.)

13. Contract Relations.—Assuming that the road is well designed, it is necessary to get it well built. Sound business relations between contractors and the directing engineering organizations is manifestly the only possible means of getting good work at a reasonable cost. Any element of unnecessary risk or uncertainty which the contractor must assume raises the bid price of the work. Any doubt as to whether the work will be let provided a reasonable bid is secured tends to keep away responsible contractors. Prompt decision and uniform treatment are essential. Reasonable profits are necessary to insure good work, for the community usually gets just what it pays for.

The author has heard public officials say that they figured to catch a sucker at every letting. They often did, but the result was that they either got a rotten job or had the difficulty of finishing the work themselves with all the usual complications. Fortunately, this attitude has few supporters to day and it may be stated as a general principle that uncertainty must be eliminated as far as possible, reasonable prices must be paid, and the size of contracts should be varied in order to interest organizations that can best handle the road in question.

The uniform use of long-mileage contracts is no more desirable than the use of short contracts. Large organizations have a high overhead and equipment charge and there are generally not enough of them to insure lively competition. They can afford to provide labor-saving machinery, which is a distinct advantage during times of labor shortage. The award of long contracts to large organizations is probably desirable for high-priced rigid pavements, particularly in sparsely settled communities.

Short contracts tend to encourage competition. They can generally be finished in one working season, which eliminates considerable uncertainty in the labor situation and the cost of materials. They can generally be handled with local labor, particularly in the well-settled districts. They cause less inconvenience to the traveling public during construction. They are probably desirable for the construction of roads in well-settled districts, particularly where the macadam form of pavement is used.

Uncertainty in bids can be reduced by complete and definite plans and specifications that have the reputation of being enforced; by definite statements of the requirements of materials and the location of acceptable supplies of these materials; by the publication of the engineer's estimate of cost, with a statement as to the maximum bid that will be considered in awarding the contract; and by the provision that, in case a responsible contractor makes the low bid under the limit stated and no award is made, he will receive a reasonable fee for making the bid.

To determine reasonable prices, every large state organization can afford to develop a construction department which can do

certain jobs each year to gage reasonable construction costs and to take over for completion any contracts that may be canceled for non-performance.

14. Proportion and Economy in Design. *The Relative Importance of the Detail Elements of Design.*—Most road work can be classed as a step in progressive improvement; the highway is gradually bettered from a trail to a high-class, modern, heavy-traffic thoroughfare as its use or prospective use warrants the expenditure. In the majority of cases the money at hand is not sufficient for the complete construction of all the features that are desirable even at the time when the improvement is made, and it is never sufficient to build a road that will completely fill the requirements of the future. Some features have to be omitted or slighted. It, therefore, seems well worth while to encourage, first, the construction of reasonably good fundamental elements which act as a basis for the final improvement, and then, in logical order, as many of the other desirable parts as can be built.

It certainly pays to construct what is done so that it can be readily strengthened and widened as the future requires, without losing the benefit of the previous work. The following tentative list illustrates an order of importance of design elements which probably applies to most cases with some minor variations:

DESIGN FEATURES

1. Selection of the best general route:
   a. Best location for the development of the territory.
   b. Longest open season.
   c. Least rise and fall.
   d. Length and cost.
2. Selection of the most natural engineering location following the desired general route:
   a. Reasonable grades.
   b. Exposure. Avoid north exposure and areas of deep snow.
   c. Character of excavation. Avoid rock, slides, etc.
   d. Drainage problems. Avoid flood areas, stream crossings, etc.
   e. Avoid artificial restrictions, such as section-line locations, etc.
   f. Avoid needless railroad grade crossings.
3. Detail requirements of design:
   a. Reasonable maximum grade, considering future requirements.
   b. Economical intermediate grades.
   c. Safe and economical alignment, considering future requirements.
   d. Width of roadway safe for traffic, eliminating dangerous ditches.
   e. Width of roadway convenient for traffic.
   f. Sufficient culverts and bridges to protect the roadway, considering the future.
   g. Permanent construction of these culverts and bridges.
   h. Sufficient width of clearing for sun to reach road.
   i. Safety provisions. Protection for traffic at dangerous places.
   j. Provision of liberal width of right of way, considering future widenings and developments.
4. Improvement of the road surface:
   a. By selective soil treatment.
   b. By gravel, chert, macadam, etc.
   c. By rigid pavements.
5. Improvements for the future:
   a. A higher-grade surface.
   b. A wider hard surface.
   c. Provision of sidewalks for pedestrians.
   d. Planting trees, etc.
   e. Illumination.

An examination of the roads in almost any locality leaves the impression that a little more emphasis on and attention to the better construction of the fundamental features will add to the reasonable proportion of design and be a move in the right direction.

The following typical cases illustrate the usual problems that occur and indicate their general solution.

General Solutions, Pioneer Districts.—Where no road exists and the funds are entirely too small for good construction, a sufficiently cheap design is used to complete the entire length. Under these conditions the only requirement that must be met is the proper selection of general route, although it is probable that for the greater part of the distance the final engineering location can be followed. Considerable work of this kind has been done in the Southwestern states, and the solutions are ingenious. Satisfactory wagon and automobile trails have been constructed under favorable conditions for as low as $20 per mile, while in difficult locations advantage has been taken of all possible expedients to keep the cost down.

Where a poor but usable road exists between terminal points, or for a portion of the distance, either the uncompleted or the worst sections of the route are first considered. Under such circumstances the funds are generally sufficient to permit a moderately good engineering design, which must provide for a reasonably good grade and drainage scheme on the improved sections, although the drainage structures may be cheap and temporary and the roadway narrow.

Where a fair road has been previously built over the entire route, no improvement should be attempted unless it provides for a first-class engineering design of grades, alignment, section, and permanent drainage structures.

Where a first-class natural-soil road is in use, the next step in progressive improvement requires either selected soil, gravel, or hard-surfaced construction of the traveled way.

General Solutions, Well-settled Districts.—The application of the order of importance of design elements for hard-surfaced pavement work can be shown by three cases:

Under the most favorable conditions in rich communities, the improvement is considered final and its design is based on an effort to obtain the most useful, and in the end the most economical, form of construction regardless of the first cost. In this case all the engineering requirements may be fulfilled.

In many communities, however, the funds are only sufficient to build a moderately good pavement, which will have to be bettered by reconstruction in a few years, to meet the increasing demands of the traffic. An improvement of this kind should be permanently and completely designed for proper grades, alignment, section, drainage and safety provisions up to a certain reasonable limit and the balance of the money spent on the best type of hard surface that can be afforded.

The third case is reconstruction, which usually confines the problem to consideration of the most suitable type of resurfacing, utilizing previous work to the best advantage. It also sometimes involves improved relocation.

Reasonable Economy in Design.—The mileage to be constructed is so great and the amount of money involved so impressive that it

seems desirable to use all reasonable care to produce as many mile of road as possible with the available funds. During the year 1913–1920 the author has made a careful review of some 2000 mile of road plans from different sections of the country with the idea o forming a reasonable conclusion as to the trend of highway desig and to see how closely current practice follows the well-recognize principles of highway engineering. The results of the analysis c these plans were, roughly, as follows: About 25 per cent could b classed as first-class designs from any economical standpoint. Prac tically all the designs showed minor wastes, but for the plan classed as good, revisions would not result in any practical advan tage. About 75 % cent of the plans showed a material expenditur of money for which no adequate return was obtained, amountin to from 5 to20% of the cost. On some of the roads which, as built served the traffic well, this excess might better have been spent o other jobs. On some of the roads, which, as built, were not up t the requirements of the traffic, the waste might better have bee applied to their own improvement in fundamental features.

The general faults most noticeable were:

Too much spent on the reduction of intermediate grades.

Too much spent to obtain long, straight grades.

Too much spent on sections with deep ditches.

Not enough spent on realignment at dangerous locations.

Not enough spent on relocations necessary to get reasonabl maximum grades.

Not enough spent on long-span bridges.

Too much spent on width of pavement.

Not enough spent on depth of pavement.

Too much spent on imported materials where local material were available in limited quantities.

One of the objects of this book is to discuss in detail variou proved means of effecting economies without reducing the usefu ness of the roads. At this point, however, it is not necessary to d more than to indicate the different parts of design that are partic ularly susceptible to such saving.

Systematic grading design will often reduce the work from 500 t 2500 yd. per mile, amounting in money, on an average, to from $50 to $3000 per mile. The proper use of local material, particularl in foundations, is a large factor in economy and will often reduce th cost from $1000 to $3000 per mile. Reasonable variations in pave ment width and in the thickness of surfacing courses is effective and in many cases saves from $1000 to $2000 per mile. A ver conservative estimate of savings due to these systematic mino alterations is from $1000 to $2000 per mile. These savings are no spectacular for any one job, but if consistently used their advantag on any large program is very evident. They will more than pa for all the necessary engineering work in connection with the entir program. The small additional work required for a careful analysi is the best possible engineering investment for the community tha can be made.

Tests of Designs.—It is certainly well worth while to test out eacl finished design to see if it complies with the general principles whicl

have been discussed and also with the detail economics that will be taken up later. The following list of questions indicates in a general way the points to be considered:

QUESTIONNAIRE

Is the alignment suitable for all reasonable requirements of the future?
Is the ruling grade suitable for all reasonable requirements of the future?
Is the section, ditch to ditch, safe and suitable for present traffic?
Is the right of way wide enough for future requirements?
Are there ample culverts for all requirements of the future?
Are the culverts proportioned properly as to size, considering run-off?
Are the culverts long enough to be safe and large enough to maintain?
Are the bridge superstructures strong enough for present traffic?
Have all permanent culverts and bridges been designed strong enough and wide enough for, say, 50 years?
Are the bridge abutments for new temporary superstructures solid enough for future permanent superstructures?
Are the ditches road ditches and not farm drainage ditches?
Are the safety provisions real safeguards or are they only warnings?
Is the road surface thick enough to handle present traffic without foundation failure, considering the subsoil conditions?
Is the road surface wide enough for present traffic?
Is the surface of the general type required by present traffic?
So much for proportion—now for economy:
Does the grade line conform with the principles of economical design?
Do the sections fluctuate to conform to economical design?
Has the selection of pavement type been based on the most economical use of local materials?
Has the design been varied to use limited supplies of local material with short hauls?
Is the width reasonable, and has it been varied on a road that has heavy traffic part of the distance and light traffic part of the way?
Has the depth of macadam been varied to meet the different requirements of the soils and kept to a reasonable minimum?
Have the culverts and bridges been designed for the most economical type for the span in question?
Have the types of culverts been varied to get the cheapest result, considering local materials, in comparison with market quotations and cost of long hauls on imported materials?
Are the specifications flexible enough to permit reasonable use of local material?
Does the testing laboratory make an effort to approve the reasonable use of local material, or is it inclined to hold arbitrarily to the highest standards, regardless of the relative importance of the job in hand?

The designer should, however, bear in mind that imperfections in construction and intermediate factors make too close a theoretical design impracticable and that a certain factor of safety must be provided in all his plans for such possibilities. The application of this to the different elements of design will be discussed throughout the book.

Economic Engineering Design.—Economic engineering design balances value against cost and considers the following factors:

1. Traffic classification (volume and kind).
2. Economical design and value of improved location, grades, and alignment.
3. Suitable pavement types, based on traffic classification.
4. Subgrade soils.
5. Economic design of alternative pavement types considering soil and traffic.
6. Local and imported material available.
7. Comparative cost estimates (alternative types):
   a. Construction.

b. Maintenance.
c. Renewal.
d. Motor operation costs.
8. Reasonable maximum and minimum expenditures.
a. Economic value of improvement based on reduction in travel cost
b. General intangible value.
9. Recommended design considering both technical and non-technica factors.

The economic designs of Bridges and Grade Crossings are dis cussed in Chapters 4 and 9.

1. *Traffic Classification.*—Estimates of present and future traffi are discussed on page 32 and general traffic classification on page 46

2. *Economical Design and Value of Improved Location, Grades and Alignment.*—The second part of the analysis considers a stud of relocation, grade reduction, and alignment.

Practice in matters of alignment are based entirely on the facto of safety and no consideration is given to reduction in motor opera tion cost, for, while motor operation costs are increased by danger ous alignment, they are not greatly affected by minor improvement in relatively safe alignment. Dangerous alignment is eliminate on the basis of general or intangible benefit, which at the same tim gives some economic cost benefit. (See Chap. II for the effec of alignment on cost.)

For deriving the approximate value of proposed grade reduction or relocations, Tables 5 and 6 (p. 12) give a rough approximatio of the capitalized motor operation cost per foot of distance travele by an average volume of 100 vehicles daily average mixed traffic fo each rate of grade from level to 10%. Table 6 assumes one-hal traffic up and one-half down each grade, and is very simple to use In comparing proposed alternate locations or profiles using differen rates of grade, it is necessary to compute only the sum total distanc in feet of each rate of grade used on the different designs and t multiply by the money value given in the table, summing up th resultant products for each proposed design. The total differenc multiplied by the volume of future traffic considered reasonabl gives a quite rational basis for conclusions as to the relative value o the alternate designs considering motor operation costs. Th relative cost of the alternate proposed routes are then balance against their relative value. An example of such a tabulation i given on page 57.

The values for the different rates of grade range from $9 per foot per 100 vehicles daily to $127. The derivation of Table 6 ha appeared in various publications. For the last 8 years it has bee used by the author in connection with all grading designs for whic he has been responsible. It shows quite plainly that the reductio of natural grades of 4% or less are rarely justified. For higher rate of grade each case is a special problem, three examples of which wil be given to illustrate the value of an economic analysis of this kind

The first example is the Woodville Bristol Springs Highway in the Finger Lake District of New York. This is a rough, hilly county and the original road had dangerous alignment and 15% grades Two relocations were considered, one based on straight alignment and 10% grades which is the extreme maximum for such conditions.

he other on 7% maximum grades, greater distance, and safe but rooked alignment. Each of these locations had certain backers nd the road was deadlocked. An economic analysis was applied ased on the preceding data. This analysis showed that the value f the 7% location from the standpoint of motor operation probably nore than justified the increased cost of this location. The 7% was dopted.

The second example refers to the design of approach grades to a ighway bridge over a railroad crossing. This crossing occurs on a elatively unimportant state road. The following is quoted from ne recent official report where Table 6, page 12 was used in guring the economics of the design.

'OMPARISON CAPITALIZED MOTOR OPERATION COST, OLD AND NEW PROFILE (ROAD 1392)

(Based on column 1, Table 6, page 12)

Rate of grade, %	Estimated capitalized cost per 100 vehicles daily per foot of distance	Old profile		New profile	
		Length, feet	Amount 100 vehicles daily	Length, feet	Amount 100 vehicles daily
1.0 or less	$ 9.10	8,300	$75,530	7,900	$71,890
1.5	9.12	800	7,296	400	3,648
2.0	9.15	1,200	10,980	1,700	15,555
2.2	9.17	200	1,834	800	7,336
2.4	9.19	500	4,595	700	6,433
2.6	9.21	600	5,526	300	2,763
2.8	9.23	1,000	9,230	800	7,384
3.0	9.25	800	7,400	1,600	14,800
3.2	9.28	800	7,424	500	4,640
3.4	9.31	500	4,655	500	4,655
3.6	9.34	400	3,736	1,000	9,340
3.8	9.37	100	937		
4.0	9.40	400	3,760	700	6,580
4.2	9.45	300	2,835	200	1,890
4.4	9.50	400	3,800	400	3,800
4.6	9.56	500	4,780	100	956
4.8	9.63	200	1,926	200	1,926
5.0	9.70	300	2,910	100	970
5.2	9.80	100	980	100	980
5.4	9.90	100	990		
5.6	10.00	400	4,000	300	3,000
5.8	10.10	400	4,040	400	4,040
6.0	10.20	.....	......	800	8,160
6.5	10.70	.....	......		
7.0	11.20	100	1,120		
7.5	11.85	500	5,925		
8.0	12.50	200	2,500		
8.5	13.25	100	1,325		
9.0	14.00	100	1,400		
9.5	14.75	.....	......		
10.0	15.50	200	3,100		
100 vehicles daily total................			$184,534	.....	$180,746
500 vehicles daily total................			$922,000	.....	$904,000

Maximum economic value of grading $18,000. ($922,000–$904,000)

"Construction cost is increased but motor operation cost decreased b the adoption of lower rates of grade. The use of a 7% approach grad advocated by Mr. . . . . instead of the 8.5% recommended woul increase the construction cost $14,000 over the cost of the 8.5%. While i is impossible to figure the capitalized cost of motor operation exactly, it i not likely that the reduction in operation cost would warrant an increase i construction cost of over $6,000, assuming 300,000 cars yearly, which is liberal allowance for future traffic. The increased cost of construction i out of all proportion to the benefit derived, which indicates that 8.5 grade is preferable to 7.0% from the standpoint of economic benefit."

The 8.5% rate was adopted.

The third example covers the use of these data in connection wit deriving the value of a proposed highway improvement. Th following is quoted from the official report on Road 1392, which i a Class III crossroad on the state system.

"The existing grades are, in the main, easy, with a few short steep grade of 8 to 9%. The new profile, as a rule, follows the existing road closely, wit short grade reduction using 6% maximum grades. The total rise and fa for the old and new road is about the same. The proposed grading wi have some effect in reducing motor operation costs, but is largely useful i providing a convenient width for traffic and a smooth bed for the pavemen In figuring the economic value of the improvement grade reductions ca be given some weight for this road. Total grading cost estimated at $32,00 Total economic benefit of grading estimated at $18,000, allowing 200,00 vehicles yearly, which is liberal for this highway" (see tabulation page 5 for detail method).

3. *Suitable Pavement Types Based on Traffic Classification.*—Th discussion of this part of the design was given on page 46. Table 1 gives the summarized results.

TABLE 13.—GENERAL SUITABILITY OF TYPES

Class I roads, special-service roads, 2000 or more vehicles daily (10-hr. count in summer)	Class II roads, ordinary mixed traffic, 800 to 2000 vehicles daily (10-hr. count in summer)	Class III roads, ordinary mixed traffic, 300 to 800 vehicles daily (10-hr. count in summer)	Class IV roads, local traffic less than 300 vehicles daily (10-hr. count in summer)
Asphalt block on concrete base Brick block on concrete base Bituminous concrete on concrete base Reinforced cement concrete Stone[1] block on concrete base	Bituminous[2] concretes on old firm macadam base Small block pavements with flexible joint filler on old firm macadam base Reinforced cement concrete Penetration bituminous macadam	Bituminous macadam Water-bound macadam (oiled) Bituminous gravel Gravel (oiled)	Macadam (oiled) Gravel (oiled) Sand clay in districts not subject to severe winters
WIDTHS OF PAVEMENT[3] (In feet)			
18–20, with additional width of macadam shoulders	15–18, with additional stone shoulders	12–16	8–12

[1] Special conditions only.
[2] The use of these types on newly built macadam is not safe practice.
[3] Extra width on sharp curves.

4. *Subgrade Soils.*—The character of the subgrade soil controls the pavement design: While the authors have a great respect for recent soil research, they do not consider it practicable to make laboratory analyses of soil samples. The procedure advocated and carried out on all roads for which they have been responsible is a rough classification, station by station, made by their most experienced field men. They interview each property owner and road commissioner for the location of soft spots and investigate the character of the soil for the entire length of the road by examination of existing cuts and by bar soundings and gas pipe core samples, where necessary, for depths to at least 3′ below the proposed grade of the improvement. The results are tabulated under the following general soil classification, which are considered sufficiently accurate for all practical purposes in designing new pavements: Gravel, Coarse Sand, Sandy Loam, Loam, Clay Loam, Ordinary Clay, Heavy Wet Clay, and Quicksand.

For reconstruction designs of old macadam roads the depth of the existing macadam is determined and also its general condition, whether firm or mixed with the underlying soil. The underlying soil is classified as for new construction.

5. *Economic Design of Alternate Pavement Types, Considering Soil and Traffic.*—In order to make rational comparative estimates of final highway costs, it is necessary to adopt adequate pavement depths for the different types. Pavement strength affects not only construction cost, but also maintenance and renewal costs. Inadequate strength reduces first cost, but increases maintenance and renewal. The authors' experience for the last 20 years indicates that the pavement depths given in the attached tables are adequate, and result in economical final cost, including maintenance and renewal. These depths are affected by the subsoil and traffic. The depths recommended consider not only the soils but whether the pavements are in cut or on high fills.

They are based on maximum vehicle loads of 28,000 lb., for year-round travel, Class I and II highways, reduced to 12,000 lb. during the spring thaw for macadam roads on Class III and IV highways.

The macadam depths range from 6 to 30″ and the rigid-pavement depths from 6 to 13″, with additional gravel or stone subfoundations where necessary (see Tables 14 and 15).

Pavement Widths.—Pavement width depends, first, on safety and convenience, and, second, on cost. Experience indicates that for traffic of less than 300 daily, single-track pavements 8 to 12′ wide with a grading width of 20′ serve satisfactorily. For Class III traffic (300 to 800 daily), normal widths of 12 to 16′ are moderately safe and convenient, with a grading width of 22′ for turn-out traffic. Extra width on sharp curves is provided for all roads of Classes III, II, and, I (see p. 132). For Class II traffic (800 to 2000 daily), normal widths of 16 to 18′ with special gravel shoulders are both safe and economical from a maintenance standpoint. On Class I traffic (over 2000 daily), 18 to 20′ normal widths with special macadam shoulders serve well up to about 6000 vehicles in 12 hr. For volume of traffic above this count, the construction of parallel routes is advocated, to reduce congestion, but where this is not

Table 14.—Recommended Total Depths of Flexible Pav ments in Localities Subject to Severe Winters (in Inches

Class I Traffic (over 2,000 vehicles daily, 10-hr. count in summer
(Macadam not usually economical on Class I roads)

Soil	Location of road		
	In cuts or on shallow fills less than 1 ft. deep	On intermediate fills 1 to 3 ft. deep	On high fills over 3 ft. deep
Coarse sand and fine gravel	9 to 10	9 to 10	9
Loams	10 to 14	10 to 12	10
Ordinary clays	15 to 21	12 to 16	11
Heavy clays and fine sands	22 to 30	14 to 18	13
Class II Traffic (800 to 2,000 vehicles daily, 10-hr. count i summer)			
Sand and gravel	8 to 9	8 to 9	8
Loams	9 to 12	9 to 11	9
Ordinary clays	12 to 18	11 to 15	10
Heavy clays and fine sands	18 to 28	13 to 16	12
Class III Traffic (300 to 800 vehicles daily, 10-hr. count i summer)			
Sand and gravel	7 to 8	7 to 8	7
Loams	8 to 10	8 to 9	8
Ordinary clays	12 to 16	9 to 14	9
Heavy clays and fine sands	18 to 24	12 to 15	11
Class IV Traffic (less than 300 vehicles daily)			
Sand and gravel	6 to 7	6 to 7	6
Loams	7 to 9	7 to 8	7
Ordinary clays	10 to 15	8 to 12	8
Heavy clays and fine sands	15 to 22	10 to 14	9

possible 27 or 36′ widths of pavement are used. As a general rul it does not seem wise to cater to the policy of concentrating traffi on a few roads and it is believed better to limit pavements to the 2 width for single roads except near cities where unavoidable concer tration occurs. For discussion of road capacity see page 28. Fc roads carrying more than 1500 vehicles daily the shoulders shoul be wide enough to permit all cars which are parked or stopped fo repair to be entirely off the pavement proper.

The consideration of width completes the factors of design whic control the quantities for comparative estimates of pavement cos

6. *Materials Available.*—The local and imported materials con trol unit cost estimates. Investigations of the sources of suppl are routine procedure and no special comment is required in regar to this factor, except that it is not wise to demand the same standar

of excellence for materials on roads carrying less than 800 daily as it is for highways carrying over that amount.

7. *Comparative Pavement Cost Estimates.*—Comparative cost estimates include the cost of construction, maintenance, and renewal. Construction cost estimates for different types of pavement suitable to the general class of traffic the improvement will serve is the next step in procedure. These estimates are based on the design data previously discussed and on the selection of the cheapest source of material supply suitable for each type of pavement. For western New York macadam pavements of adequate depth cost from $1.50 to $3.80 per square yard and rigid pavements of adequate strength from $2.30 to $5 per square yard, depending on soils, materials, and traffic. It is very evident that the wide range makes a careful analysis necessary to determine which type has the advantage for any specific case.

Maintenance costs shown in Table 16 are based on general records for the last 20 years modified by consideration of selected roads which approximate the modern design standards previously discussed and which have received proper maintenance. The attached table of maintenance cost, represents what is considered a fair average for properly designed pavements during the period recommended as reasonable economic life before renewal becomes necessary. These costs do not agree exactly with reported general averages, as a large percentage of existing mileage is entirely too weak for modern traffic and also a considerable mileage of rigid pavements has been in service for such a short time that maintenance charges are less than normal.

In a general way, the maintenance of well-designed and maintained macadams will range from 1.5 to 7 cts. per square yard, per year, depending on traffic. The cost of rigid pavement maintenance over a long term of years will probably run between 0.5 to 3 cts. per square yard per year, depending on the type and the traffic. These costs do not include incidental maintenance of shoulders, ditches, etc., which are considered as a separate item.

The average yearly renewal costs are based on western New York records for the past 20 years modified by the fact that funds for reconstruction have lagged behind the necessities of the situation, which results in low reported costs and extremely rough highways during the last few years before reconstruction. The renewal costs given are based on probable length of life, during which the pavements will not become disagreeably rough (250″ per mile Vialog rating) without excessive maintenance ($1000 per mile year maximum). Under these conditions the life of macadam pavements is estimated between 5 to 17 years with an average yearly renewal cost of between 6 to 20 cts. per square yard, depending on the traffic. The life of rigid pavements will range from 8 to 30 years, with renewal costs of between 7 to 17 cts. per square yard.

Motor Operation Costs.—Consideration of the relative cost of motor operation over the different types of pavement completes the economic comparison of alternate designs.

There is no possibility of deriving exact costs of operation over the different types, as there is a wide range in power used, tire wear,

TABLE 15.—COMPARISON OF RECOMMENDED THEORETICAL DEPTHS OF CEMENT CONCRETE BASES FOR DIFFERENT PAVEMENTS UNDER DIFFERENT MAXIMUM LOADS ON DIFFERENT SOILS (IN INCHES)

NOTE.—The last column gives prevailing practice in base depth for each type (1919 to 1922).

Pavement	Recommended depths of cement concrete bases based on modified corner load formula $d = P\sqrt{\frac{JW}{S}}$						Current practice 1919–1923, inches
	3½-ton truck 16,000-lb. gross load		5-ton truck 22,000-lb. gross load		7-ton truck 28,000-lb. gross load		
	Ordinary subsoils, inches	Gravel or macadam, inches	Ordinary subsoils, inches	Gravel or macadam, inches	Ordinary subsoils, inches	Gravel or macadam, subsoils, inches	
Plain concrete: (1:1½:3 mix)	7.2 & 7.8	6.5 & 7.0	7.9 & 8.8	7.2 & 8.0	**8.7 & 9.7**	**8.0 & 8.8**	6 to 10
Plain concrete: (1:2:4 mix)	7.6 & 8.2	6.9 & 7.4	8.4 & 9.2	7.6 & 8.3	**9.2 & 10.0**	**8.4 & 9.1**	
Reinforced concrete (mesh and bar): Central longitudinal joint (1:1½:3 mix)	6.3 & 6.9	6.0 & 6.4	6.7 & 7.5	6.2 & 6.8	**7.3 & 8.2**	**6.5 & 7.3**	
Reinforced concrete (corner and exterior tie bars only): Central longitudinal joint 1:1½:3 mix	6.5 & 7.0	6.0 & 6.4	7.0 & 7.8	6.3 & 7.1	**7.7 & 8.5**	**7.0 & 7.7**	5 to 9
1:2:4 mix	6.9 & 7.4	6.4 & 6.8	7.4 & 8.2	6.7 & 7.4	**8.1 & 9.0**	**7.4 & 8.1**	
Monolithic brick 4-in. brick on 1:1½:3 concrete base	4.5	4.0	5.0	4.5	**6.0**	**5.5**	4.0
2-in. to 3-in. *Asphaltic concrete on concrete base:* (1:3:6 mix)	6.5	6.0	7.0	6.3	**7.5**	**6.8**	5 to 8
(1:2½:5 mix)	6.0	6.0	6.5	6.0	**7.0**	**6.3**	
2-in. *Asphalt block on cement concrete base:* (1:2½:5 mix)	6.5	6.0	7.0	6.3	**7.5**	**6.8**	5 to 8
4-in. *Brick* (mastic joint filler) *on cement concrete base:* (1:3:6 mix)	6.8	6.2	7.6	6.9	**8.3**	**7.5**	
(1:2½:5 mix)	6.5	6.0	7.0	6.3	**7.8**	**7.1**	6 to 8
4-in. *Brick (cement grout filler):* (1:3:6) concrete base	5.5	5.0	6.1	5.5	**6.7**	**6.2**	5 to 8
(1:2½:5) concrete base	5.2	5.0	5.7	5.2	**6.3**	**5.7**	
5-in. *Stone block: Cement grout filler:* (1:2½:5) concrete base	5.2	5.0	5.7	5.2	**6.3**	**5.7**	5 to 7

NOTE—See bottom page 63 for explanatory note.

etc. of a vehicle traveling over any type of pavement due to the relative perfection of the surface, which is affected by excellence of construction, age of pavement, and excellence of maintenance regardless of the type of pavement being investigated (see Figs. 8 and 9).

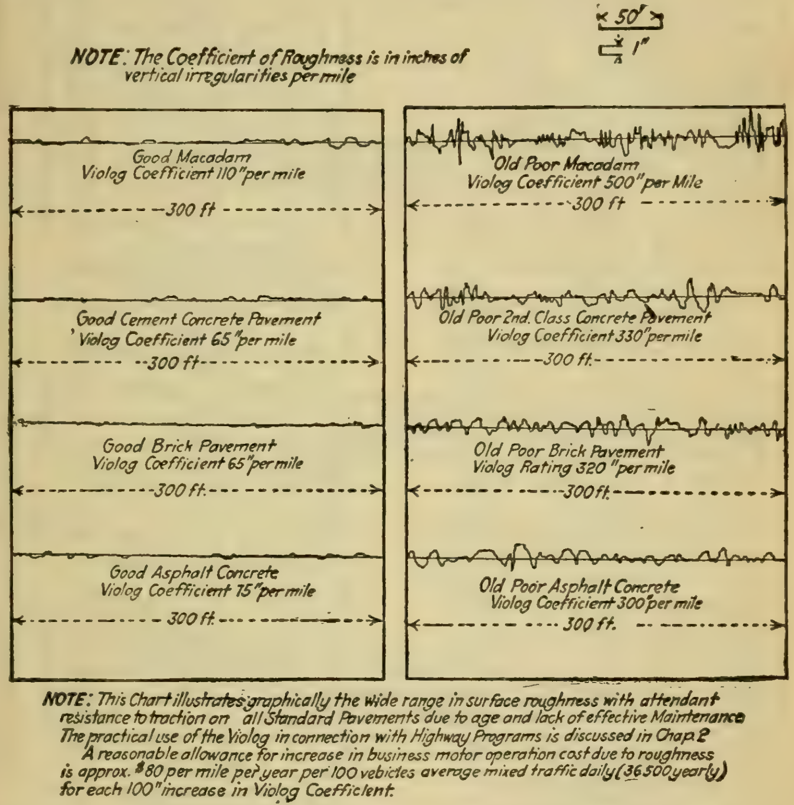


FIG. 8.—Vialog records of surface roughness (showing effect of age).

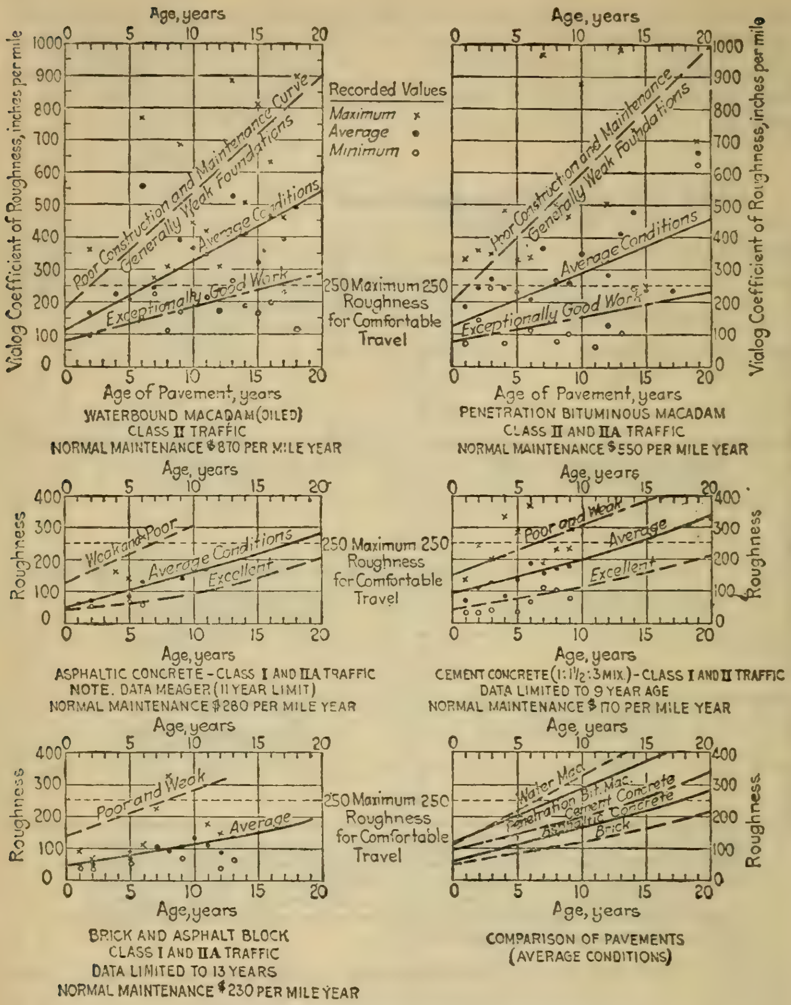
It is, however, possible with the data at our disposal (1926) to compare the cost of vehicle operation over the two general classes of pavement surfaces in common use and arrive at general conclusions, although the range in possible values is quite large. For (text continued on page 67.)

NOTE TO TABLE 15

NOTE: Where two depths are given the smaller is for interior areas and the larger for exterior edge depths. Where one is given it applies to interior areas.

Typical recommended Pavement Sections showing details are given in Chap. VI under the discussion of each type of pavement. The object of this table is to give a tentative basis of estimating the amount of materials and the cost per square yard for the different types suitable for different maximum load conditions.

Table 15 in conjunction with Table 14, page 60, provides a means of computing reliable comparative cost estimates for all ordinary standard types based on equal strength.



GRAPHS SHOWING WIDE RANGE AND AVERAGE VALUE OF VIALOG CO-EFFICIENT OF ROUGHNESS FOR DIFFERENT PAVEMENTS AT DIFFERENT AGES.

(NEW YORK STATE 1923)

Based on average maintenance, that is, no specially high maintenance has been used to hold the roughness to a specified maximum. Reconstruction is resorted to when normal maintenance becomes ineffective.

NOTE: *These graphs show the wide range in results obtained under Public Works Programs and show conclusively the distinct advantage of good Engineering Control. Any type of pavement well designed, constructed and maintained will give satisfactory results as far as traffic operation cost is concerned.*

To anyone personally familiar with this district these records have a human as well as a scientific interest. It is possible to trace the gradual loss or gain in interest in the success of the various types depending on the sympathies of the different administrations and they also show the effect of knowledge and experience of the inspectors with different types.

FIG. 9.

TABLE 16.—PROBABLE AVERAGE MAINTENANCE AND RENEWAL COSTS FOR DISTRICTS SIMILAR TO WESTERN NEW YORK (1922)

Computed for normal conditions. Exceptionally favorable conditions in regard to excellence of original construction and to maintenance appropriations and personnel might easily reduce maintenance and renewal costs 20 to 30 per cent (see Table 105, Chap. VII).

Type of pavement	Width, feet	Average depth, inches	Construction costs		Yearly maintenance	
			Contract cost per square yard pavement only	5 Per cent interest on cost	Pavement only per square yard	Shoulders, ditches, guard rail, etc.
Column No. 1	2	3	4	5	6	7
Class 1 Traffic (2000 or more Vehicles Daily 10-hour Count in Summer)						
Stone block on concrete base	18–20	12	$5.50	$0.275	$0.005	$0.020
Brick on concrete base	18–20	11	4.20	0.210	0.015	0.020
Asphaltic concrete on cement base	18–20	10	3.50	0.175	0.020	0.020
Reinforced cement concrete	18–20	8	3.20	0.160	0.015	0.020
Penetration bituminous macadam[1]	18–20	13	2.50	0.125	0.070	0.020
Class 2 Traffic (800–2000 Vehicles Daily 10-hour Count in Summer)						
Reinforced cement concrete[1]	16–18	8	$3.20	$0.160	$0.010	$0.015
Asphaltic concrete on macadam base	16–18	12	3.00	0.150	0.020	0.015
Brick cubes on macadam base	16–18	12	3.00	0.150	0.020	0.015
Penetration bituminous macadam	16–18	12	2.20	0.110	0.040	0.015
Waterbound macadam (oiled)	16–18	12	1.90	0.095	0.080	0.015
Class 3 Traffic (300 to 800 Vehicles Daily 10-hour Count in Summer)						
Penetration bituminous macadam	12–16	10	$1.90	$0.095	$0.030	$0.012
Waterbound macadam	12–16	10	1.60	0.080	0.060	0.012
Class 4 Traffic (Less than 300 Vehicles Daily)						
Waterbound macadam	8–12	9	$1.50	$0.075	$0.040	$0.012
Gravel[2]	8–12	10	1.00	0.050	0.040	0.012

[1] These types eventually resurfaced with asphaltic concrete or some form of standard block or cube surface.

[2] This type can be temporarily used under heavy traffic but for a volume of over 400 to 500 daily it generally develops disagreeable waves known as rhythmic corrugations.

Table 16.—Probable Average Maintenance and Renewal Costs for Districts Similar to Western New York (1922)—*Continued*

Computed for normal conditions. Exceptionally favorable conditions in regard to excellence of original construction and to maintenance appropriations and personnel might easily reduce maintenance and renewal costs 20 to 30 per cent (see Table 105, Chap. VII).

Type of pavement	Renewal[3]		Total maintenance and renewal		Total interest on construction, maintenance and renewal	
	Assumed normal life	Yearly cost for renewal	Per square yard	Per mile	Per square yard	Per mile
Column No. 1	8	9	10	11	12	13
Class 1 Traffic (2000 or more Vehicles Daily 10-hour Count in Summer)						
Stone block on concrete base	30–35	$0.100	$0.125	$1400	$0.400	$4400
Brick on concrete base	15–20	0.160	0.195	2150	0.405	4450
Asphaltic concrete on cement base	10–15	0.170	0.210	2300	0.390	4300
Reinforced cement concrete	10–15	0.160	0.195	2150	0.360	4000
Penetration bituminous macadam[1]	5– 9	0.200	0.290	3200	0.420	4600
Class 2 Traffic (800–2000 Vehicles Daily 10-hour Count in Summer)						
Reinforced cement concrete[1]	15	$0.145	$0.170	$1,700	$0.330	$3,300
Asphaltic concrete on macadam base	12	0.150	0.185	1,850	0.335	3,350
Brick cubes on macadam base	12	0.160	0.195	1,950	0.345	3,450
Penetration bituminous macadam	10	0.120	0.175	1,750	0.285	2,850
Waterbound macadam (oiled)	8	0.110	0.205	2,050	0.300	3,000
Class 3 Traffic (300 to 800 Vehicles Daily 10-hour Count in Summer)						
Penetration bituminous macadam	12	$0.100	$0.140	$1,100	$0.240	$1,900
Waterbound macadam	10	0.070	0.140	1,100	0.220	1,800
Class 4 Traffic (Less than 300 Vehicles Daily)						
Waterbound macadam	12	$0.060	$0.110	$ 650	$0.180	$1,100
Gravel[2]	8	0.030	0.080	500	0.130	800

[1] These types eventually resurfaced with asphaltic concrete or some form of standard block or cube surface.

[2] This type can be temporarily used under heavy traffic but for a volume of over 400 to 500 daily it generally develops disagreeable waves known as rhythmic corrugations.

[3] Based on maximum vialog coefficient of 250 in. per mile without excessive maintenance charge.

purposes of comparison, the ordinary rural pavements are classed as follows:

Class A. Brick, bituminous concretes, and Portland cement concrete.

Class B. Bituminous macadam and water-bound macadam or gravel with bituminous surface coats.

Table 4 (p. 11), based on investigations at the Iowa State College in conjunction with U. S. Bureau of Roads, shows a difference in average vehicle operating cost of approximately 0.5 ct. per mile, or 5% of the total operating cost of vehicles in favor of Class A surfaces as compared with Class B. This is considerably in excess of the authors' data.

The authors' investigations as published in "Rural Highway Pavements" in connection with Vialog records in western New York indicate that, making due allowance for average roughness over the total life of the pavement, snow and ice in winter, etc., the difference in operating costs for well-maintained Class A and B surfaces does not probably exceed 3% of the cost of gasoline, oil, tires, and repairs or approximately 0.14 cts. per average vehicle mile. (See Chap. VII, p. 545). As discussed on page 10 business travel is approximately 50% of total travel which must be considered in computing the actual loss to the community at large from the use of Class B surfaces.

The following tabulation indicates roughly the loss per mile of highway per year for different volumes of travel and the capitalized value of this yearly loss at 5%, which represents the added justifiable cost of Class A surfaces over the cost of Class B surfaces due to difference in vehicle operating costs. This tabulation is based on the authors' figures of 0.14 cts. given above. The following quotation strengthens the discussion.

"In computing the total yearly cost of a pavement to the community it is just as well to give some weight to the item of reduction in operating cost.

"For average conditions in Division N. 4, western New York, considering construction, maintenance, renewal, interest on construction, and difference in motor operation cost, the general conclusion to be drawn is that the macadam type of surface usually becomes uneconomical from a business standpoint at a volume of traffic of between 1000 to 2000 vehicles daily. At this point an old macadam road can be resurfaced with asphaltic concrete and brought up to the operation efficiency of Class A pavements."

Examples of Economic Comparisons of Pavements.—To illustrate definitely the use of the foregoing data in comparing the economic value of different pavements, considering construction maintenance, renewal, and motor operation costs, two examples from recent design reports will be cited.

Road 1392.—This road is a Class III traffic crossroad on the state system. For purposes of economic comparison a volume of traffic of 500 daily average has been adopted and the use of three alternate pavement designs considered: water-bound macadam, oiled, bituminous macadam, and reinforced cement concrete. A 16′ width has been adopted, as, while this may not be justified by the normal volume of local traffic, this road will be subjected at inter-

TABLE OF INCREASED VEHICLE OPERATION COSTS, CLASS B PAVEMENTS AS COMPARED WITH CLASS A PAVEMENTS

Number vehicles per day		Increased cost of yearly vehicle operation				Capitalized value of increased cost			
Total	Business only	Per mile		Per square yard 18′ pavement		Per mile		Per square yard 18′ pavement	
		Total	Business only	Total	Business only	Total	Business only	Total	Business only
100	50	$ 50	$ 25	$0.005	$0.002	$ 1,000	$ 500	$0.10	$0.05
500	250	250	125	0.025	0.012	5,000	2,500	0.50	0.25
1,000	500	500	250	0.05	0.025	10,000	5,000	1.00	0.50
2,000	1,000	1,000	500	0.10	0.05	20,000	10,000	2.00	1.00
3,000	1,500	1,500	750	0.15	0.075	30,000	15,000	3.00	1.50
4,000	2,000	2,000	1,000	0.20	0.10	40,000	20,000	3.90	1.95
5,000	2,500	2,500	1,250	0.24	0.12	50,000	25,000	4.80	2.40

vals to detour traffic from Route 6, the main east-and-west route. The economic comparison of types is tabulated as follows:

ECONOMIC COMPARISON OF TYPES, ROAD 1392

Type	Estimated construction cost per square yard	Interest on initial cost at 5%	Estimated yearly maintenance per square yard	Estimated average yearly renewal per square yard	Increased motor operation, Class B, per square yard	Total yearly cost, per square yard
Cement concrete........	$2.30	$0.115	$0.010	$0.11	$0.00	$0.235
Bituminous macadam....	1.60	0.080	0.035	0.11	0.01	0.235
Water-bound macadam....	1.50	0.075	0.065	0.10	0.01	0.25

NOTE.—For conditions prevailing on this road there is very little difference in final economy for these three types.

The second example used is the Mt. Morris Village Highway, which is Class I, Stas. 26 to 48, and Class II, Stas. 0 to 26. The economic analysis given below shows an advantage for bituminous macadam from Stas. 0 to 26 and for cement concrete from Stas. 26 to 48.

COMPARISON, STAS. 0 TO 26

Type	Estimate cost of pavement, square yards	Yearly interest on construction square yards	Yearly maintenance, square yards	Renewal, square yards	Motor operation	Total yearly cost, square yards
Bituminous macadam...	$1.60	$0.08	$0.035	$0.12	$0.015	$0.25
Cement concrete........	2.70	0.135	0.01	0.14	0.00	0.285

COMPARISON, STAS. 26 TO 48

Type	Estimated cost of pavement, square yards	Yearly interest on construction, square yards	Yearly maintenance, square yards (Table 16)	Renewal, square yards (Table 16)	Motor operation	Total yearly cost, square yards
Bituminous macadam...	$1.90	$0.095	$0.05	$0.16	$0.03	$0.335
Cement concrete........	2.70	0.135	0.01	0.14	0.00	0.285
Asphalt concrete........	3.10	0.155	0.02	0.15	0.00	0.325
Brick.........	4.10	0.205	0.015	0.13	0.00	0.350

While these analyses of final cost have some bearing on type selection, it is very evident from the small differences in total final cost, which are in many cases invalidated by poor construction or maintenance procedure, that type selection is more affected by the necessities of the situation expressed in terms of limitation of funds, initial cost of construction, and local preferences for certain types than it is by total final yearly cost; that is reasonable maximum and minimum expenditures for construction in a given case should be based on common sense rather than solely on an analysis of this nature.

8. *Reasonable Maximum and Minimum Expenditures and Recommended Design, Considering Both Technical and Non-technical Factors.*—In deciding on maximum and minimum expenditures, both direct reduction in motor operation cost and indirect intangible community benefits are considered. In computing the direct saving due to the improvement 1 ct. per ton-mile is a common allowance (see p. 14) of the value of our proposed pavement improvements. No allowance is made for minor differences between modern macadams or rigid-base pavements. To convert this direct yearly saving into permissible construction cost, multiply the total yearly saving in motor operation cost by 10. This procedure is based on maintenance and renewal records (Table 16) which show that the total yearly cost including interest on first cost, maintenance and renewal depends more on volume of traffic than on type of pavement within the general classes of traffic adopted and that it amounts to from 8 to 11% of the initial cost of construction.

On this basis Table 7 (p. 15) was derived. This table gives a reasonably close basis for estimating permissible average maximum expenditures based on travel cost saving due to pavement construction. To get the total permissible cost, add the value of grading and relocation to the pavement benefit.

Intangible general community benefits are more indefinite. Intangible benefits are expressed in terms of a rise in the general living standards of the community and, while they cannot be given an exact money value, a very definite idea of the types of road which must be constructed in order to obtain these benefits is derived. General community benefits can be obtained by what are called general-utility highways, which permit year-round travel for the normal business of the community with moderate comfort and with excessive maintenance cost (see p. 6).

Extreme refinements of grade or pavement surface which bring motor operation cost to a minimum are no factor for such roads. General-utility roads include all types of pavement, depending on the volume of traffic, and cost from $3000 to $60,000 per mile exclusive of bridges and grade-crossing eliminations. The usual costs for different volumes of traffic are given in Fig. 3 (p. 16). These costs are minimum permissible expenditures for any particular road and control expenditure where the direct reduction in travel cost does not permit an increase over these amounts.

To illustrate definitely the application of these principles, two examples are given, the first from official report on Road 1392, and the second from Mt. Morris village.

Example 1. *Road* 1392. "*Reasonable Maximum Expenditure.*—Reasonable expenditures based on reduction in traffic operation cost can be estimated approximately as follows:

"Grade reduction value (Art. 3 of this report, see p. 58) is estimated at not to exceed $18,000.

"Pavement value is roughly estimated as follows: The old existing road is a narrow gravel road in fairly good condition; the new pavement will not probably reduce the cost of operation over 1 ct. per vehicle mile, but it will add materially to the safety and convenience of operation, which are classed as intangible benefits. Actual reductions in operation cost (see Table 7) will not probably justify construction expenditures of over $16,000 per mile for 500 vehicles daily, or a total of approximately $60,000 for the entire length of this road. The total maximum economic value, including grading and pavement, does not probably exceed $75,000. Any expenditure over this amount must be charged to convenience, pleasure, and other desirable intangible benefits.

"This indicates that caution should be exercised in running the cost up needlessly.

"Total estimated construction costs for different widths of different types are tabulated below:

Type of pavement	Widths of pavement					
	8′	10′	12′	14′	16′	18′
Water macadam.	$70,000	$78,000	$ 85,000	$ 99,000	$ 99,000	$105,000
Bituminous macadam..........	73,000	80,000	88,000	94,000	102,000	109,000
Cement concrete.	85,000	96,000	108,000	116,000	128,000	138,000

"In order not to exceed the economic limit of $75,000 based on reduction of travel cost, we would be limited to a 10′ width of water-bound macadam oiled. A pavement as narrow as this is not in accord with our general policy, which limits the width to 16′, on the score of intangible benefit where the proposed road will at times carry detour traffic of a main route.

"We, therefore, recommend the use of 16′ width of bituminous macadam, estimated to cost $100,000. This recommendation seems to be warranted, as this type will satisfy traffic demands without running the construction cost up needlessly and without increasing the total final cost of road, including maintenance, renewal, and motor operation over and above the final cost from the use of a more expensive first-cost pavement.

"REMARKS.—Actual procedure on this road was as follows: Plans were first prepared for cement concrete pavement. Before these were let, the administration changed and the plans were revised for bituminous macadam, 7″ boulder base, 3″ imported slag middle course, and 2½″ imported limestone top; engineer's estimate of cost, $123,000. This road was constructed on this basis for $102,000 actual contract cost; the pavement proper cost $65,000, or approximately $1.75 per square yard. This final solution was an improvement over the first plans. A careful engineering design could probably have decreased the cost at least $8000 to $10,000 as shown in the body of this report by a more complete utilization of local materials and more variation in depth to meet varying soil conditions and a somewhat more economical grading design."

Example 2. *Mt. Morris Village* (see p. 69).—"From the standpoint of both original and final cost there is a every evident advantage for macadam from Stas. 0 to 26. The local people have no particular preference as to the type of pavement for this portion of the road. Local preference would be the only factor entitled to modify decisions based on the cost analysis, provided the additional cost is paid locally. As this factor need not be considered, we recommend bituminous macadam pavement from Stas. 0 to 26.

"From Stas. 26 to 48, local preference must be considered. The village proposes to pay the additional cost introduced by such preference as to type and extra width desired. Under these conditions the cost analysis is of value only as indicating proper state cooperation. Article 10 gives alternate total estimates of cost to enable the village to come to a reasonable decision as to the type they will ask for."

Recommended State and County Cooperation Based on Final Cost (*Art.* 7).—"The state would be justified in limiting their cooperation to the cost of a 16′ bituminous macadam pavement from Stas. 0 to 26 and an 18′ reinforced concrete pavement from Stas. 26 to 48 and 880 to 883 plus with ordinary surface-drainage provisions. This would amount to approximately $35,000. This is not an excessive amount if the funds are available (see Table 7), considering the volume of traffic served (about 1500 daily).

"I understand the rules of the Department limit cooperation to the construction of a 16′ road of the same type already constructed outside of the village. This rule would limit cooperation to a 16′ bituminous macadam which would cost approximately $30,000 for this locality. Under these circumstances it seems desirable to set the cooperation at $30,000.

"REMARKS.—Actual procedure on this road was as follows: The contract was let for reinforced cement concrete pavement from Stas. 0 to 26 and the brick pavement from Stas. 26 to 48, the local people paying the excess cost over and above the state fund limit advised in the foregoing report. This was a rational solution, considering local preference and willingness to assume added cost."

These examples complete the description of procedure and the practical part that economics play in design. The discussion shows quite plainly that economic analyses are desirable but that they are only one element in the decision.

Conclusion of Chapter.—This chapter may be briefly summarized as follows:

1. From the standpoint of economic return on road investments, it is desirable to limit the type of improvements to standards of general utility until a general system has been accomplished, particularly if the program is financed by a general tax levy.

2. Efficient maintenance of both the old existing roads and the new improved roads is the only possible means of giving moderately good general traffic service within a reasonable time.

3. It is probably desirable in most cases to begin by concentrating effort and at least 50% of the total available highway expenditure on a rapid construction program for certain main roads constituting say, from, 5 to 15% of the total road mileage. Such roads should, if possible, be built up to truly economic engineering standards of general utility.

4. After this is accomplished, it generally seems desirable to raise the standard of the entire balance of the system as can best be done. This may require low, makeshift engineering standards of pavement design for the first stages of improvement, depending entirely on the financial strength of the district. Under a reasonable tax distribution it is generally possible to improve the system gradually by successive stages up to the standards of general utility, provided traffic is subjected to reasonable regulation.

5. Unrestricted traffic makes it impossible to make any progress with local service roads in the poorer districts, as the comparatively light roads that these districts are able to finance are destroyed faster than they can be built. Rigid traffic regulation on a rational basis, depending on the local conditions, is a more positive help in local road improvement programs then even quite generous state-

aid moneys. Where it is impossible to finance roads that will economically handle heavy trucking, it is obvious that the only solution requires the elimination of such units during the first stages of improvement. Even the first stages of improvement, however, should probably permit the use of 2½-ton trucks.

6. The reasonable distribution of the tax burden and sound methods of raising construction and maintenance funds are fundamentals in the success of any program.

7. The classification of roads tends to stabilize procedure through successive administrations and tends to encourage a rational distribution of funds and well-balanced engineering type selection.

8. Sound general policy in the matter of handling growth in traffic volume apparently favors the principle of ultimately distributing traffic over moderate-priced parallel routes rather than by concentration on a few extremely wide and extremely expensive highways.

9. Sound general policy in the matter of pavement type seems usually to lead to the use of flexible pavements for the earlier stages of improvement programs, gradually strengthening the foundation and improving the character of the surface up to practically any standard of convenience, except for a very small percentage of the mileage (special-service roads), on which the outset there is no doubt that the rigid type of pavement is the most economical investment.

10. The success of any program depends on the ability of the executive to develop an efficient design, construction, and maintenance organization. In highway work as in any other line the whole matter hinges on personnel, and this particular phase of the problem can be well handled only under a liberal policy of public service salaries and recognition of ability.

The following chapters consider the details of engineering design.

CHAPTER II

LOCATION—GRADES AND ALIGNMENT

Location, grades, and alignment are the most permanent elements of a highway improvement and are entitled to reasonable forethought and to as much money as required to meet future engineering requirements suitable for the final stages of improvement of the road in question.

LOCATION

Selection of Route.—The selection of route depends on the purpose of the road, the topography between controlling points, and the stage of development of the community. Each case is a special problem, but there are certain fundamental facts worth considering. The basis of decision on general routes rests on good common sense and is not entirely an engineering problem. The road must go where it will do the most good, and it is up to the engineer to locate it in detail along the general route. The route location rests on reasonable answers to questions of the following nature: Where will the road do the most good to develop the natural resources of pioneer districts, or how can this route be located to serve the greatest number of people in well-settled communities, or how can this scenic road be built to give the most pleasure? If an attempt is made to solve all these problems strictly on the basis of the shortest distance and the easiest grades between terminals, the engineer would be in hot water. Any satisfactory solution considers the broad engineering principles of short distances, reasonable grades, and the smallest amount of rise and fall, but the final decision does not always rest on close analytical ton-mile cost hauling figures. To illustrate: recreational roads through national and state parks or forests are usually laid out to afford the most pleasure; grades and distance are sacrificed to obtain vistas, bold outlooks, and to reach points of historical interest or summer resorts. The cost of operating a car on such roads has no bearing on its usefulness, and a location based on a close analytical ton-mile hauling cost would be merely ridiculous. Consider a national highway from New York to San Francisco. Some through touring will occur, but its volume is very light and the cost of additional distance is not of any consequence to this class of traffic. More touring will go one-half or one-quarter of the way, but even this is of no great factor in comparison with short-distance traffic on the route. To lay out any long route on the basis of the shortest distance and easiest grades between terminals for through traffic and to disregard passing through or close to the most cities and villages on the route are

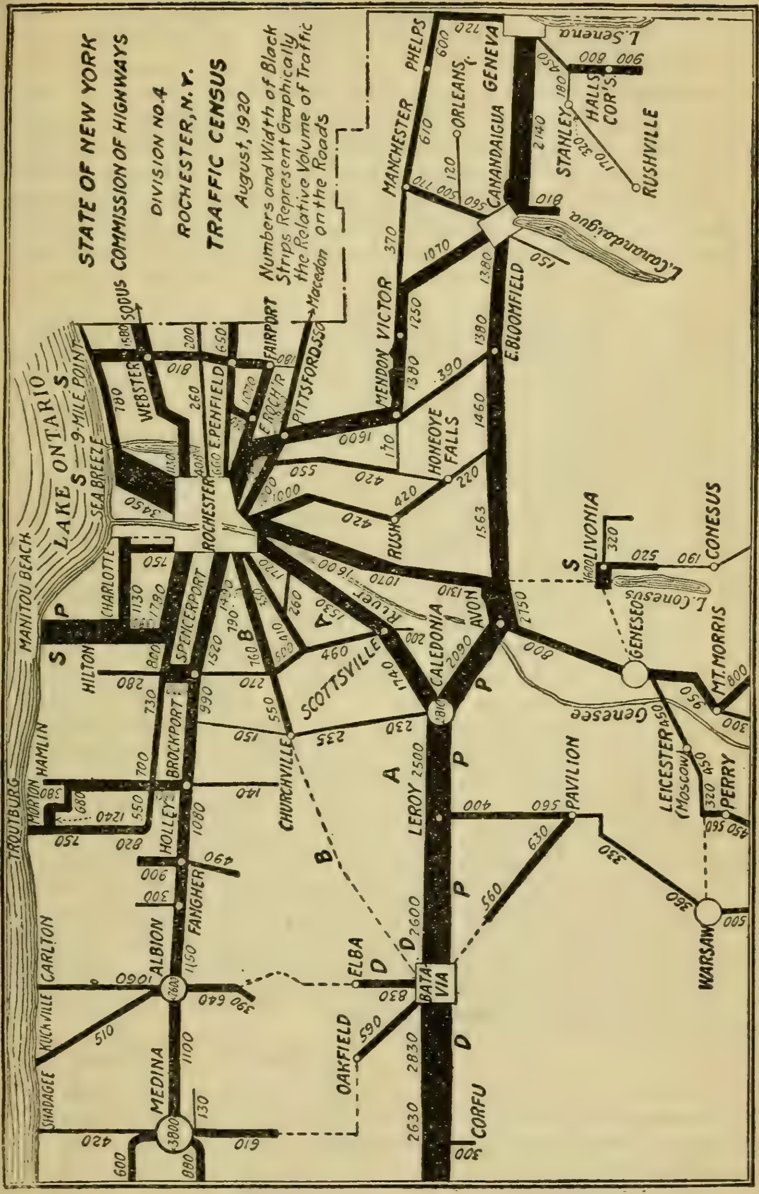


FIG. 10.—Traffic map. State Road System Division No. 4 Western New York.

evidently poor policies. This illustration is exaggerated to bring out the principle of route selection in well-settled communities, which is, namely: To pass through the most populous areas, and either close to or through the most cities and villages that can be consistently done without too much additional distance. This same principle applies to state and to purely local roads and may be summed up as direct contact with the greatest number of people.

As the distance between controlling points becomes less the factor of commercial hauling has a larger bearing on the selection of route until a point is reached where the engineering requirements of location govern the selection. That is, a reasonably low ton-mile hauling cost governs the short integral parts of any long-route location. At the present time (1926), motor freight hauling in competition with railroads is rarely economical for a distance of over 80 to 100 miles between terminals. This limit will probably fluctuate, but it is not likely to increase much, and for the time being it does not seem desirable to permit the factor of long-distance motor freight hauling to influence the selection of routes between large cities directly connected by rail over 100 miles apart. Where large cities are located closer than this, and there is a large volume of heavy motor hauling, it is possibly better to save distance by omitting some of the local service. Where large cities are isolated, heavy trucks rarely operate to outlying towns farther than 30 to 40 miles. Take a definite instance to illustrate this principle (see Fig. 10, p. 75). Rochester, N. Y., a city of about 280,000 population, is located 80 miles from Buffalo, a city of approximately 400,000 people. The first state route completed between these cities is shown in Fig. 10 as far as Batavia, a city of 14,000 people, and is designated on this map as Route A. This route was laid out in conjunction with state Route 6, the main east-and-west route, on the principle of local service, and it has served very satisfactorily for through traffic also. From the standpoint of through traffic between Rochester and Buffalo, the route marked B on the map (Fig. 10) is the logical route and this will undoubtedly be built in the near future.[1] That is, experience indicates that it is better to care first for the local service and then in the future, as traffic requires it, build new routes or partially relocate old routes for the further advantage of long-distance travel. A comparison of these two routes between Rochester and Batavia follows and shows the distinct advantage of Route B from the standpoint of through travel and of Route A for local service.

	Route A	Route B
Length, miles	37	31
Total rise and fall, feet	1850	1400
Number of railway shipping points served	15	9
Total railroad crossing	13	4
Railway grade crossings	9	1
Overhead or subway railway crossings	4	3

To give an idea of the traffic on this route in 1919 the following census (average 10-hr. count in summer season) is shown at different points:

[1] Route B completed in 1926.

Route A (Traffic Census)

	Horse traffic		Motors		Total
	1 horse	2 horses	Cars	Trucks	
Between Rochester and Scottsville	30	30	850	100	1010
Between Scottsville and Caledonia	70	40	700	110	920
Between Caledonia and Le Roy	85	65	1600	180	1930
Between Le Roy and Batavia	15	10	1200	85	1310

As an additional point of interest, the new proposed through Route B from Bergen to Batavia fails to pass through two small settlements Byron and South Byron, because it would be necessary to use 2 miles extra distance for this local service—that is, Route B primarily considers through service. These villages can be served by a stub line. It is often desirable to by-pass villages and even certain cities on through routes on account of traffic congestion and the annoyance and danger of a large volume of high-speed traffic in the communities in question. These places can be served by stub lines or supplementary loops. As a rule, villages desire to have the main roads pass directly through them on account of the state aid for their street paving and the additional business derived from traffic, but the last feature does not amount to much unless they happen to be so located on the line that the traffic would naturally stop for some reason.

Pioneer Location.—To give an idea of the factors entering into the selection of routes in mountain districts, an example will be cited from Colorado, namely, the Bardine-Redstone road through the Sopris National Forest. This road was selected for improvement and advanced in order of construction by the U. S. Forest Service for the following reasons: An examination of the map will show that by a short road about 30 miles long over McClure's Pass the Carbondale and Paonia valleys can be directly connected. Without this road, it took a day's travel by rail to get from Carbondale to Somerset. The second reason for the road was to open up a promising farming section along the upper Blackwater, which had heretofore been confined to a cattle and sheep range on account of the impossibility of getting produce to the railroads. By the construction of moderatlely low-cost natural-soil road on a 5 or 6% grade over the low pass 3000′ above the valleys, intercommunication and new territory could be developed and a day's time in travel saved between two flourishing sections.

The foregoing discussion indicates, in a general way, some of the factors governing route selection.

Engineering Location.—A good detail location along the required general route results in the most effective road for the traffic that can be obtained for the available funds. Desires for perfection are controlled by the limitations of the community pocketbook. It is

obviously desirable to obtain short distance, easy alignment, reasonable grades and to avoid locations which call for extremely expensive construction, such as rock work, flood, areas, etc. It is obviously desirable to avoid locations where snow drifts badly or fails to melt promptly in the spring, as the number of days in a year that a road is open has a large effect on its usefulness. It is obviously desirable to avoid needless railroad grade crossings. A summary of the engineering principles of location is given on page 81.

Extreme Refinements Impracticable.—An economic engineering location for commercial roads might be theoretically developed on the lowest ton-mile hauling cost to traffic. Practically, it is not yet reasonable to do this in many cases for the ordinary highway, and the reasons for disregarding this factor as the deciding element seem sound. Railroads have spent large sums to reduce the ton-mile cost and in their location the engineers make extremely careful comparative estimates of construction cost against operating cost. They consider the elements of shorter distance, curvature, light and heavy grades, etc. Many railroad engineers wonder why these considerations are not given more weight on highway work, considering the increase in mechanical transport. One of the evident reasons is that railroads get a direct tangible money return in dividends for their expenditure, and the return to the community on a public-road investment is too intangible. As a matter of interest, however, Tables 5 and 6 (p. 12) give approximate relation to distance, rise, and time as it affects operating costs. These data have been used by the author for some time as a basis for judgment in the comparison of lines.

It is undoubtedly true that, to get the full value of an improved road system, the engineering location must be made for the most efficient use of motor transport, but at the present time there is no possibility of obtaining or any justification for spending extremely large sums to reduce the hauling cost below that obtained by the usual modern highway design. If truck owners provided unlimited funds, a careful analysis would be justified on special commercial roads, but the following facts must be considered: the location of roads in well-settled districts are practically confined to existing rights of way except for minor relocations to avoid extreme grades or for safety reasons. These rights of way were not necessarily laid out with any regard to economic road location and, in fact, were often arbitrarily fixed by land section lines or locations where a poor road could be constructed in the past without much labor or cost. The cost of new rights of way for entire new locations and the difficulties of acquiring are prohibitive at this stage of development in road building except for unusual cases. The improved roads of today are only a progressive stage in the development of highway transport. The demand for them and the satisfaction in their use lie mainly in the fact that they provide a firm surface which can be used the year round, that they materially cheapen the cost of hauling, and that they make the use of light automobiles feasible for long and fast trips. The community is willing to pay a certain amount for the improvement in road conditions which the usual practice in modern road construction gives, but it is not willing to

pay large additional sums for further reduction in ton-mile hauling costs. In the first place, only a comparatively few men would get a direct benefit from such expenditure. The indirect return to the community is too intangible. Much of the road traffic is pleasure traffic, and a few more gallons of gas mean nothing. If the owner did not spend his surplus for gas, he would spend it for ice-cream soda or the movies. There seems to be no way of making the few road users who would benefit by a further reduction in hauling cost pay the price of the necessary construction. It may be that for certain toll roads some time in the future or for exceptional cases in metropolitan districts a ton-mile cost location analysis could be used, but as yet this standard is too high for the usual road.

This does not mean that the engineer should not make an effort to get the best possible location that he can, but he should bear in mind that the first principle of general policy considering a comprehensive road system is mileage service, and aim to keep cost to a reasonable minimum in order to get the greatest mileage of road that will serve the purposes of the great majority of road users. For all roads except special-service commercial roads probably 90% of the traffic does not demand nor would it be particularly benefited by excessive refinements. Poor grade or alignment should never be used on high-class roads, as they are the fundamental features of the improvement and the only permanent features of construction. Liberal expenditures are justified, but there is a limit to expenditures for refinements that reduce mechanical operating costs to a minimum. The detail analysis of grade, alignment, section etc. given in Chap. II and III are intended to bring out the requirements of road design that are necessary for the satisfaction, safety, comfort, and comparative cheap hauling requirements of the average road users. These are the fundamentals which must be provided. Additional refinements beyond the fundamental requirements are desirable if the funds are available from the proper sources. By the "proper sources" is meant the actual road users benefited by the additional cost of construction.

Saving in distance is valuable; saving in total rise is valuable; easy grades and the elimination of sharp curves are desirable. Every effort is made to accomplish these results, utilizing the existing roads where it is necessary, making minor relocations to avoid extreme grade or danger because the sentiment of the community approves these measures, but always bearing in mind that today and for a long time to come mileage is the prime requisite of programs. It is possible in the sparsely settled communities to make better engineering locations, as far as right-of-way handicap is concerned, but in these districts shortage of funds often plays havoc with intentions.

Value of Saving Distance and Rise.—It is well to bear in mind what distance saving is worth and what a saving in total rise is worth. The data given are, of course, of only general value, as the fluctuating cost of motor operation, the types of hauling, and special conditions of all sorts affect the figures. They, however.

show in a general way that it is well worth while to reduce traffic losses arising from these elements of needlessly poor location or design.

A. R. Hirst gives the following conservative figures on the value of saving distance:

"If the very conservative sum of 10 cts. per mile is allowed for each mile of travel saved, the saving of a mile in distance on highways carrying the following average number of vehicles per day will save the traveling public the given amount per year, which is the interest at 5% on the amount given in the third column."

TABLE 17.—VALUE OF A MILE IN HIGHWAY DISTANCE SAVED

Average number of vehicles per day	Saving to owners per year	Saving capitalized at 5% equals
100	$ 3,650	$ 73,000
250	9,125	182,500
500	18,250	365,000
750	27,375	547,500
1,000	36,500	730,000
2,000	73,000	1,460,000
5,000	182,500	3,650,000
10,000	365,000	7,300,000

The value of eliminating rise cannot be figured with any degree of accuracy, as there are too many indeterminate and variable factors, but in the authors' opinion it is not likely that the capitalized value of saving in yearly operation due to eliminating 1′ of rise and fall per 100 vehicles per day on long routes will exceed $60 on light grades or $400 on heavy grades. For small grading reductions on short hills the time factor is of no consequence and the practical value of saving a foot rise and fall is not probably more than one-third of these figures.

It is very evident that considerable expenditure is justified to reduce distance and rise, but it is also evident that it would be impracticable to carry this method of location to its logical conclusion by expenditures in any way approximating the figures given. That is, the location of a free public road financed by a general tax with no direct revenue return can hardly be analyzed from the same point of view as a trunk-line railroad.

Relocations of Existing Highways.—Everyone would prefer to have scientifically located highways. A great many engineers believe that the time has come to make extensive relocations. It is self-evident that relocations which reduce the construction cost of the proposed road as well as reduce motor operation costs should be made at once. It is surprising how often even such relocations are not made, and it is desirable to impress on the men in charge of surveys that they should continually bear in mind the necessity of such relocations and not feel that they must follow the present road lines where these conditions prevail. There seems to be no question that expenditures for relocations necessary to obtain reasonably good grades and alignment are justified at the present stage of road

programs, but it is believed that extensive relocations involving excessive refinements must be gradually worked out except for a few extreme cases and that practically it will be easier to accomplish and fairer to the general public to do most of this work under reconstruction programs financed by direct vehicle taxes rather than to attempt it at this time in the first stage of improvement.[1]

In case a relocation is necessary, no halfway measures should be allowed. In too many cases even on fairly important state roads in rich communities relocations have been made on the basis of 9% grades when it was perfectly possible to get 7% or less. Halfway treatments of this kind are worse than nothing.

To illustrate present practice on relocations, the following quotation from the Iowa Highway Department "Field Manual" is given. The limiting grade of 6% mentioned does not agree with the recommendation given on page 105, but the general scope of the data strengthens the discussion at this point.

Relocation.[2]—"Where the topography is flat or gently rolling the profiles readily lend themselves to satisfactory grades at a moderate cost, and relocations to any extent are seldom necessary. But in the rougher country, relocations will frequently be necessary and the field man must constantly watch for opportunities to better the alignment, avoid steep hills, or improve stream crossings by relocations. The necessity for or advisability of relocating must always be balanced against the cost, and, in general, it is true that a proposed change of any magnitude is advisable only when it can be shown that such change will be economical or will produce a decidedly better road. It is therefore important that the cost of relocation be thoroughly investigated. In this connection the field man must remember to take into consideration the various improvements along the existing road, such as farm buildings, orchards, permanent bridges and culverts, heavy cuts and fills, etc.

"The following instructions should be followed:

"*a.* In all cases where it appears that an excessive amount of earthwork will be required to reduce the present road to 6% grades, the possibility of relocations to reduce grades to 6% or less shall be fully investigated.

"*b.* In cases where there is a succession of grades which may be reduced to 5 or 6%, but which cannot be reduced below that figure without considerable work, the question of relocation should be fully investigated.

"*c.* In case of doubt as to the feasibility of any relocation, a survey should always be made.

"*d.* In all cases where relocations are surveyed a survey shall be made on the old road also.

"*e.* In the case of minor relocations the margins of the old roadway should always be shown by a sketch indicating the old roadway by dotted lines, and by data in the cross-section notes. In such cases the survey of the old road may consist only of extending the cross-sections over the same.

"*f.* The notes shall show which location is to be used or shall state that the determination of which route to follow cannot be made until the notes are worked up in the office. The chief of party shall enter this notation in the field notes after consultation with the district engineer."

Summarized Principles of Location.—Climatic, drainage, and soil conditions govern a location in respect to avoiding bad snow conditions, flood areas, needless stream crossings, needless railroad grade crossings, slide or swamp formations, and excessive rock work. The general requirements of line and grade discussed in this chapter are summarized as follows: the various principles are repeated conversely under the headings of Grade, Alignment, Distance, Rise and Fall, and Cut and Fill Grade Reductions.

[1] See pp. 12, 13 for an approximate basis of comparing the value of alternate location.

[2] "Field Manual," Iowa Highway Dept.

1. *Reasonable maximum grades are essential. Recommended reasonable rates for various kinds of roads are given on page 105. The following treatment is allowable to get a reasonable maximum:*

a. Any expenditure necessary.

b. Distance may be increased in order to get a reasonable maximum grade, but should not be increased for a fixed rise to reduce grades below a reasonable maximum.

c. Poor alignment may be used if necessary to get a reasonable maximum grade if funds are low, but poor alignment should never be introduced to reduce grades below a reasonable maximum. Where poor alignment is necessary, maximum rates must be reduced at the danger points (see p. 117).

d. For a fixed rise and distance, it is generally better to use a short-length of reasonable maximum and the balance of the distance a low rate than to use a uniform moderate-rate grade for the entire distance; this is not strictly in accord with the principles of cheap motor operation (Table 6, p. 12), but the net practical results are generally better. This means that, if a road is running up a valley on an easy grade and must leave the bottom land and climb on a side-hill location to reach a pass, it is generally better to make the climb as short in distance as possible, as a side-hill location usually introduces poor alignment and generally increases the excavation per mile over a valley location.

2. *Alignment should be made as safe as possible considering the funds available. Safety of traffic governs alignment practice. Cost of traffic operation has no practical effect.*

a. Good alignment should never be sacrificed to reduce grades below a reasonable maximum (for safe alignment practice see p. 120).

b. Good alignment may be sacrificed to get a reasonable maximum, but this condition necessitates the reduction of grade at the danger points (see p. 117).

c. Improved alignment warrants increased distance only when danger is eliminated. Increased distance is not warranted merely to make an easy curve easier.

d. It is better to use a steeper grade (up to a reasonable maximum) with good alignment than to use poor alignment and a lower rate.

e. Exceptionally good alignment (practically straight) may in some cases warrant an increase in the reasonable maximum grade above the rates recommended on page 105. This modification would not, however, apply unless it was impossible to locate and grade the lower-rate location so that the sight distance in it was at least 250′ and grades over 8% are the source of many accidents even where the alignment is straight.

f. An alignment and grading design which results in a sight distance of 250 to 350′ is safe and desirable, but large expenditures to increase still further the sight distance must be used with caution unless the funds are practically unlimited. Increase in maximum grade above the recommended maximum in order to increase sight distance above 250 to 300′ is rarely warranted.

3. *Short distance is desirable, provided considerations of safety, rise and fall, or reasonable maximum grades do not modify the conclusions.*

a. Distance may be increased to reduce danger by better alignment at bridge approaches, railroad crossings, or to avoid difficult topography. Recommended minimum radius of curvature are given on p. 120.

b. Distance should be increased to get a reasonable maximum for a fixed rise, but rarely to reduce the grade below a reasonable maximum for a fixed rise.

c. Distance should never be increased to reduce rise and fall on grades of 2% or less.

d. Distance may be increased to reduce rise and fall on grades over 2% (use Table 6 for comparisons of this kind), but for grades not exceeding the maximum it is rarely desirable to increase distance unless a noticeable rise and fall can be eliminated by a small additional distance. For ordinary easy-rolling topography the principle of the straight-line location is generally sound.

4. *The elimination of needless rise and fall is desirable modified by certain conditions.*

a. The elimination of rise on steep grades is desirable. Distance may be increased to accomplish this, provided the disadvantage of increased distance is balanced against the value of less rise (see Table 6, p. 12).

b. The elimination of rise on grades of 2% or less is of no value from a practical standpoint.

c. Adverse grades may be used to eliminate dangerous alignment or shorten distance, provided the shorter distance is of more value than the disadvantage of the extra rise (see Table 6).

Summary of Cut and Fill Grade Reductions.—Grade reductions by cut or fill assume that the road location is fixed for some reason and that further improvement must be by cut or fill. The distance is always fixed. Reasonable maximum grades are essential.

a. For a fixed rise there is no practical advantage in reducing the rate of grade below a reasonable maximum.

b. Reduction of total rise and fall on steep grades is desirable.

c. Reduction of rise and fall on light grades has no practical advantage (see pp. 106 and 6).

d. The use of short adverse grades of 2% or less on a long climb has no practical disadvantage.

The sources of justifiable economy in cut and fill design lie in the use of the short maximum in connection with the long ruling grade and the use of a rolling grade profile for all intermediate rates.

The application of these principles in conjunction with the "spotting method"[1] of profile design (see p. 963) generally results in a satisfactory road at a moderate grading cost. The violation of these principles of location and cut and fill profile design occurs quite frequently.

The detail discussion of these principles follows:

GRADES

Introduction.—Grade line considers the proper use of maximum, minimum, intermediate, and adverse grades and their vertical

[1] See chap. XIV, p. 963.

curve connections. Grade-line design in connection with alignment considers the relative values of distance against rise and fall and the relative safety of light grades with curved alignment as compared with steep grades and straight alignment.

The effect of grade may be roughly summarized as follows:

An increase in the rate of grade decreases the load that can be hauled up the grade by a fixed power.

An increase in the rate of grade increases the expenditure of energy to maintain a fixed speed climbing the grade.

An increase in the rate of grade decreases the speed for a fixed power.

An increase in the rate of grade increases the wear and tear on mechanical outfits.

The mechanical energy expended in climbing is partially balanced by the reduction of energy expended on down grades.

The mechanical energy expended in climbing affords a very definite basis of comparison of the value of the travel in one direction. The expenditure of energy on down grades is indefinite, and while it affects the total operating cost on a grade, it cannot be given as much weight in the conclusion as the first method. The effect of grade on the depreciation and repair of mechanical equipment is indefinite, but it is certain that it bears some relation to the rate of grade.

Grade selection depends on considerations of safety, convenience, traffic operating cost, and the cost of construction and maintenance. Cost of traffic operation is not always the most important factor. It must often give way to considerations of safety or initial construction cost.

Reasonably low rates are desirable. The whole question of grades lies in the decision of what is reasonable for a specific case. A summary of practical rules for location and cut and fill grade line design is given on page 81.

Maximum Grades.—The subject of maximum grades will be considered from the following standpoints:

1. Relative importance of horse and automobile traffic in the selection of grade.
2. Effect of grade on horse traffic.
3. Effect of grade on motor traffic.
4. Current practice in maximum grades.
5. Practical considerations governing the selection of grade.
6. Effect of ruling grade on cost.
7. Recommended general practice.

Relative Importance of Horse and Auto Traffic in the Selection of Maximum Grade.—Tables 18 and 18*A* show the rapid growth of motor traffic on the main roads of Massachusetts and the general character of the traffic on secondary roads in western New York.

Everyone is familiar with this change in the character of highway traffic. Maximum grades have a radically different effect on horse and single-unit motor traffic, and it is necessary to come to some reasonable conclusion as to which kind of travel should govern the design.

TABLE 18

	1912	1915	1918	Per cent of increase, 6 years
Automobiles and trucks....	50,132	102,633	191,019	280
Motorcycles..............	5,034	9,520	12,708	150
Operators and chauffeurs...	65,600	133,700	225,272	240
Motor vehicle fees.........	$616,236	$1,235,723	$2,159,257	250

AVERAGE DAILY TRAFFIC ON MAIN ROADS IN MASSACHUSETTS

	1909	1912	1915	1918	Per cent of increase, 9 years
Light horse..................	91	68	40	24	−73½
Heavy horse..................	88	88	72	43	−51
Total horse..................	179	156	112	67	−62½
Automobiles and light trucks...	131	280	555	923	+604
Heavy trucks.................	...	17	45	75	+341[a]
Total motors...............	131	297	600	998	+661
Total vehicles.............	310	453	712	1065	+243

[a] In 6 years.

PER CENT OF TOTAL TRAFFIC

	1909	1912	1915	1918
Light horse...........................	29	15	5½	2
Heavy horse...........................	28	19	10	4
Total horse.........................	57	34	15½	6
Trucks................................	..	4	6½	7
Motors................................	43	62	78	87

TABLE 18A.—DAILY TRAFFIC COUNTS ON SELECTED "LOCAL-SERVICE" STATE COUNTY ROADS IN WESTERN NEW YORK

Number of roads	Number of miles	Horse traffic			Motor traffic		
		1 horse	2 horses	Total horse	Light cars	Trucks	Total motors
14	60	45	39	84	250	36	286

Horse traffic, per cent of total........................ 23
Motor traffic, per cent of total........................ 77

NOTE.—On the main state route roads the percentage of horse traffic corresponds very closely with the Massachusetts results given in Table 18.

For main roads in well-settled districts, single-unit motor traffi may well control maximum-grade design. For local service road in agricultural districts or in mountain pioneer regions, horse traffi requirements should control maximum-grade line design.

Maximum Grades from the Standpoint of Horse Traffic. *Diff culty of Ascent and Safety of Descent.*—The factors controlling eas and safety of ascent and descent have different values for differen surfaces, but as most of the roads will in time be hard surfaced an as all parts of the design should fit into the final improvement, th part of the grade argument is made primarily for hard-surface conditions.

European observers claim that on a stone road 5% is the max mum grade that can be descended safely by a trotting team withou brakes, and that 12% is the maximum that can be safely descende with brakes. By the use of the sliding shoe or locked wheel freighters in the Rockies descend 20% grades without much diff culty on ordinary natural-soil roads. Safe descent with brake need not be considered except in rare cases, as it would result in grade far beyond ordinary practice. Safe and easy descent withou brakes is more important for light rigs than for heavy hauling, bu as this class of traffic has been practically eliminated by chea automobiles it need not be given much weight. Descent, therefor plays only a minor part in grade selection except where the aligr ment is bad.

Hauling Power.—The writers know of no careful records of actu maximum loads that can be hauled up different hard-surface grades by an ordinary team; it is probably better to discuss th point theoretically, as any experiments would be affected by to many variable local conditions to be worth much as a basis of com parison. As a check on the theoretical discussion, records of load on extreme mountain grades are given on page 91, which sho that, for all practical purposes, Table 24 of theoretical loads i fairly close and is on the safe side.

A summary of Prof. I. O. Baker's discussion of maximum tear loads is given below, and through his courtesy it is possible t include a collection of tables taken from his work, "Roads an Pavements."

Various trials have determined that the normal tractive power o a horse traveling 3 m.p.h. for 10 hr. a day is approximately one tenth of its weight; that when hauling up a steep grade it can exer one-fourth of its weight for a short time; that for, a continuou exertion of one-fourth, the grade should not be over 1200′ long an if over that resting places should be provided every 600 to 800′; tha in starting and for a distance of 50 to 100′, one-half of its weigh can be used; and that the net tractive power ordinarily exerted b a horse on a grade equals one-fourth its weight—the effort require to lift itself, or approximately $0.25W - W \times$ per cent of grade expressed in hundredths, *i.e.*, $0.25W - 0.04W$ for a 4% grade This undoubtedly gives a reasonable basis for ordinary hauling conditions, but from data obtained by the author in connection with freight hauling in mountain regions it is evident that a good draft horse will exert more than $0.25W$ on moderately short, sharp

pitches of a long climb if allowed to rest at intervals of 200 to 300′. The evidence indicates that a value of $0.35W$ is about right for such conditions.

Table 19 shows the effective power developed by an ordinary team of 1200-lb. horses with moderate exertion and Table 19*A* the power of a first-class team of 1600-lb. horses exerting their full strength.

TABLE 19.—ORDINARY STOCK MODERATE EXERTION

Grade, %	Theoretical net tractive effort	Tractive effort, in pounds
Level	$0.10\ W$	240
2½	$0.25\ W - PW$	540
4	$0.25\ W - PW$	504
5	$0.25\ W - PW$	480
6	$0.25\ W - PW$	456
7	$0.25\ W - PW$	432
8	$0.25\ W - PW$	408
9	$0.25\ W - PW$	384
10	$0.25\ W - PW$	360

W = weight of team, 2400 lb.
P = per cent of grade in hundredths.

TABLE 19*A*.—DRAFT STOCK FULL POWER

Grade, %	Theoretical net tractive effort	Tractive efforts, in pounds
5	$0.35\ W - PW$	960
6	$0.35\ W - PW$	928
7	$0.35\ W - PW$	896
8	$0.35\ W - PW$	864
10	$0.35\ W - PW$	800
12	$0.35\ W - PW$	736
14	$0.35\ W - PW$	672
16	$0.35\ W - PW$	608
18	$0.35\ W - PW$	544
20	$0.35\ W - PW$	480
22	$0.35\ W - PW$	416

W = weight of team, 3200 lb.
P = per cent of grade in hundredths.

Grade and Rolling Resistance.—This power is used in overcoming axle friction, gravity resistance, and rolling resistance.

The axle friction is small, amounting to 3 or 4 lb. per ton for American farm wagons.

Grade resistance (gravity) equals load × per cent of grade expressed in hundredths, and, expressed in pounds per ton of load, equals $2000 \times P$.

The rolling resistance varies for different surfaces and for each surface depends on the diameter of wheel, width of tire, speed of travel, and the presence or absence of springs on the wagon. The best diameter of wheels, best width of tires, and the use of springs

as they affect the ease of hauling for both farm and road use ar problems for the wagon manufacturers.

Morin, a French engineer, concluded from a series of carefu experiments that the harder the surface of the road the less effec width of tire had on rolling resistance. Comparatively hard sur facing and small differences in wheel diameter are taken for grante here, and these factors can be disregarded. As a matter of interest Tables 20 and 22 are included to show the results of experiment on different soils and roads.

The question of wide tires affects road design chiefly in connectio with the distribution of load over a safe area and will be taken u under Macadam Design.

Table 23 gives the average rolling resistance in pounds per ton o load on different pavements for the ordinary farm wagon drive at ordinary speeds.

TABLE 20.—EFFECT OF WIDTH OF TIRE UPON TRACTIVE POWER RESISTANCES IN POUNDS PER TON

Ref. No.	Description of the Road Surface	Diameters of the Front & Rear Wheels respectively									
		3′–6″ & 3′–10″		3′–6″ & 3′–10″		3′–8″ & 4′–6″		3′–6″ & 3′–10″		3′–8″ & 4′–6″	
		Width				of		Tires			
		1½″	4″	1½″	4″	1½″	4″	1½″	3″	1½″	3″
1	Sod							283	239	189	228
2	Earth road (hard) ...		108					152	152	114	114
3	" " (muddy)		243	268	304	236	254			265	228
4	Sand " (hard)	199	162	171	164	141	168				
5	" (deep)	371	351								
6	Gravel road (good) ..			98	117	83	80			66	76
7	Wood Block (round)	51	49	61	70	35	46		54	28	38

[1]Pamphlet by Studebaker Brothers Manufacturing Company, 1892.

TABLE 21.—EFFECT OF SIZE OF WHEELS ON TRACTIVE RESISTANCE[1] POUNDS PER TON

Ref. No.	Description of Road Surface	Mean Diameter of Front & Rear Wheels		
		50″	38″	26″
1	Macadam, slightly worn, fair condition	57	61	70
2	Gravel road, sand 1″ deep, loose stones	84	90	110
3	" " upgrade 2.2%, one-half inch wet sand, frozen below..........................	123	132	173
4	Earth road. Dry and hard	69	75	79
5	" " ½″ sticky mud, frozen below.....	101	119	139
6	Timothy & blue grass sod, dry grass cut	132	145	179
7	" " " " " wet & spongy......	173	203	281
8	Cornfield; flat culture across rows, dry	178	201	265
9	Plowed ground; not harrowed, dry & cloddy ..	252	303	374
10	Average Value of Tractive Power	130	148	186

Experiments of T. I. Mairs at the Missouri Agricultural Experiment Station.

Ref. No.	Description of Road Surface	Width of Tire		No. of Trials
		$1\frac{1}{2}''$	$6''$	
1	Broken Stone, Road; hard, smooth, no dust, no loose stone	121	98	2
2	Gravel Road; hard and smooth; a few loose stones	182	134	2
3	" " " no ruts, large quantity of sand	239	157	1
4	" " new gravel, not compact, dry	330	260	1
5	" " wet, loose sand 1″ to 2½″ deep	246	254	2
6	Earth Roads. Loam, dry, loose dust 2″ to 3″ deep	90	106	2
7	" " " dry and hard, no dust, no ruts, nearly level	149	109	3
8	" " " stiff mud, drying on top, spongy below	497	307	1
9	" " " mud 2½″ deep, firm below	251	325	1
10	" " Clay, sloppy mud, 3″ to 4″ deep, hard below	286	406	1
11	" " " dry on top but spongy below	472	422	2
12	" " " dry on top but spongy below	618	464	5
13	" " " stiff deep mud	825	551	1
14	Mowing Land. Timothy sod, dry, firm, and smooth	317	229	1
15	" " " " moist	421	305	1
16	" " " " soft and spongy	569	327	1
17	Pasture " Blue grass sod, dry, firm, and smooth	218	156	2
18	" " " " " soft	420	273	2
19	" " " " " soft	578	436	1
20	Stubble " Corn stubble, no weeds, dry enough to plow	631	418	2
21	" " " " some weeds, dry enough to plow	423	362	1
22	" " " " in Autumn, dry and firm	404	256	2
23	Plowed " Freshly plowed, not harrowed, surface rough	510	283	1
24	" " " " harrowed, smooth, compact	466	323	1

[1] Missouri Agricultural Experiment Station Bulletin No. 39.

TABLE 23[1]

Kind of pavement	Rolling resistance, in pounds per ton of load
Asphalt	30–70
Brick or concrete	15–40
Cobblestones	50–100
Earth roads	50–200
Gravel roads	50–100
Macadam roads	20–100
Plank	30–50
Stone block	30–80
Wood block	30–50

[1] Baker's "Roads and Pavements."

Effect of Grade on Loads.—For a comparative estimate take a value of 40 lb. per ton of load, including axle friction, on macadams and rigid pavements and 100 lb. per ton for earth roads in fair shape. The resistance to the effective tractive power of the team per ton of load is therefore $40 + (2000 \times P)$ on the hard-surfaced roads, and $100 + (2000 \times P)$ for earth roads, and the maximum load expressed in tons for any grade equals

$$\frac{\text{Effective tractive power of team for that grade}}{\text{Resistance per ton of load for that grade}}.$$

Using the tractive powers of the ordinary team shown in Table 19 Table 24 is constructed. It is chiefly useful for a comparison of the effect of grade on load, but all evidence indicates that the loads given correspond closely to practice. Table 24*A* shows loads for extreme team exertion as compiled in Table 19*A*. The loads given include weight of wagon.

TABLE 24.—ORDINARY STOCK MODERATE EXERTION

Grade, per cent	Effective tractive effort, pounds	Improved roads: Resistance in pounds per ton of load	Improved roads: Maximum load, in tons	Earth roads: Resistance, in pounds per ton	Earth roads: Maximum load, in tons
Level	240	40	6.0	100	2.4
2½	540	90	6.0	150	3.6
4	504	120	4.2	180	2.8
5	480	140	3.4	200	2.4
6	456	160	2.9	220	2.1
7	432	180	2.4	240	1.8
8	408	200	2.0	260	1.6
9	384	220	1.7	280	1.4
10	360	240	1.5	300	1.2

TABLE 24*A*.—DRAFT STOCK EXTREME EXERTION

Grade, per cent	Effective tractive effort, pounds	Hard-surfaced roads		Earth roads	
		Resistance, in pounds per ton	Maximum load, in tons	Resistance, in pounds per ton	Maximum load, in tons
5	960	140	6.8	200	4.8
6	928	160	5.8	220	4.2
7	896	180	5.0	240	3.7
8	864	200	4.3	260	3.3
10	800	240	3.3	300	2.7
12	736	280	3.0	340	2.2
14	672	...	...	380	1.6
16	608	...	...	420	1.4
18	544	...	...	460	1.2
20	480	...	...	500	1.0
22	416	...	...	540	0.8

Effect of Length of Grade on Maximum Load.—In mountain-road design where a long ruling grade is used it is often economical to introduce short stretches of steeper grade to avoid extremely expensive construction and to improve alignment. In order to determine the maximum short grade (not exceeding 300 ft. in length) that can be used in connection with a long ruling grade without reducing the team load, Table 24*B* has been compiled for a 2400-lb. team.

TABLE 24*B*.—EQUIVALENT LONG AND SHORT GRADES FOR HARD-SURFACED CONDITIONS

Long ruling grades tractive effort $0.25W$, 2400-lb. team.		Short maximum grade tractive effort $0.35W$, 2400-lb. team.	
Grade, %	Maximum load, tons	Grade, %	Maximum load tons
5	3.4	7	3.7
6	2.9	9	2.8
7	2.4	10	2.5
8	2.0	12[a]	2.0

[a] Twelve per cent is the practical limit (on account of safe descent) on any road of sufficient importance to be considered from an engineering standpoint.

This principle can also be applied to a long cut and fill grade reduction with a very material saving in cost, but if used the steeper rate should not be over 250 to 300′ long and should be at the bottom of the hill.

Records of Team Loads.—H. G. McPheters and F. F. Roberts have compiled the following data on team freighting in the Rocky Mountain region. It is practical data obtained from personal experience and strengthens the force of the theoretical discussion. The loads given are net and do not include wagon weights. They represent usual freighting loads which are practical maxima.

Heber Fruitland Road, State of Utah

Daniels Canyon Section

Earth road in fair shape.
Long 8% grades.
Short 15% grades.
Net load for four-horse team, 3500 lb. (during summer).

Galena Summit Road, State of Idaho

Natural-soil road in fair shape.
Maximum grade (Salmon River side), 20%.
Maximum grade (Wood River side), 17%.
Load for one team, 1800 lb. (during summer).
Load for two teams, 4000 lb. (during summer).
Load for three teams (six horses and two wagons loaded 5000 lb on lead wagon and 4000 lb. on trail taking one wagon at a trip up the mountain).

Trail Creek Summit Road, State of Idaho

Natural-soil road (fair condition during summer).
Maximum grade, 22%.
Load for one team, 1200 lb.
Load for two teams, 2500 lb.

When freighting by teams was the principal mode of transportation, there were used on this road several outfits of 24 mules hooked to four wagons loaded as follows: lead, 14,000 lb.; lead swing 10,000 lb.; swing, 8000 lb.; and trail, 4000 lb. Two men handled the whole outfit, which was certainly a man's job.

Rocky Bar Atlanta Road Over Bald Mountain

Natural soil.
Maximum grade, 16%.
Load for one team 2000 lb.
Load for two teams 4000 lb.

A large amount of freight is carried over this road by auto trucks at the present time.

The Theoretical Advantage of Certain Grades.—From Tables 24, 24*A*, and 24*B* and the previous discussion the grades that theoretically fulfil certain traffic requirements can be selected.

1. On hard-surfaced roads the same load that can be drawn up a 2½% grade by reasonable extra exertion of a team can be hauled on a level with ease. This makes a perfectly balanced design from the standpoint of team hauling. The theoretical load is 6 tons. For earth roads 5% fulfils this same condition with a theoretical team load of 2.4 tons.

2. Five per cent is the maximum grade that fulfils the requirement of safe descent at a trot without brakes. This is of little importance under modern traffic conditions.

3. The same load that can be hauled up a 7% hard-surfaced grade can be drawn on a level dirt road in fair condition; a 7% grade therefore does not reduce the load of a team which must travel over even a level earth road for part of the distance. The theoretical load is 2.4 tons.

4. The use of short maximum grades of greater rate than the long ruling grades does not reduce the maximum load, provided they are proportioned as follows for hard pavements and do not exceed 250 to 300′ in length:

Long	5%	Short	7%
Long	6%	Short	9%
Long	7%	Short	10%
Long	8%	Short	12%

5. Twelve per cent is the practical limit of grade for even unimportant roads on account of safe team descent with heavy loads.

As a matter of fact, the selection of grade depends more on the requirements of the traffic and the topography of the country than on these theoretical advantages.

Effect of Grade Selection on Motor Traffic.—Safety, convenience limitations of load, and cost of vehicle operation must be considered.

Safety of Motor Operation.—Motor accidents are quite frequent due to the sudden application of brakes on steep hills in rainy or sleety weather where the road has a hard, smooth surface. Accidents of this kind occur even on level grades, but are not frequent up to 5% rates of grade; beyond 5% they occur with rapidly increasing frequency and become a real cause of danger on grades over 7% even when the alignment is straight. From the standpoint of safety, 7% is a maximum rate for hard-surfaced roads.

Convenience of Motor Operation.—Drivers dislike to be forced into second or low gear. If it is possible to determine approximately the rate of grade at which most cars or trucks shift gear, this information has some bearing on grade selection. It is, of course, difficult to figure this closely as motor design improves, gear ratios vary, cars run on varying degrees of efficiency, gasoline varies in quality, etc., but as a matter of interest the authors' experience indicates that the average light pleasure car of the year 1919 shifts into second gear at about 7% and that very little gear shifting is necessary on long 6% grades. W. C. Slayton, a truck fleet manager, says that his 5-ton standard gear ratio trucks generally drop into second at about 5% and that very little shifting would be required on long 4% grades. Passenger autos drop into low at about 10% and the 5-ton trucks into low at about 8%.

From the standpoint of convenience in driving pleasure cars, these premises, if they apply, indicate that if for any reason a 6% grade cannot be obtained a 10% might just as well be used and that heavy expenditure to get a 7 or an 8% has no bearing on the convenience of the road. This applies only to scenic routes. In the same way for truck hauling, if a 4% cannot be obtained there is no object from the standpoint of convenience in using lesss than an 8%. Other factors, however, apply to reduce this extreme jump,

DIAGRAM SHOWING GRADIENTS AND ROAD RESISTANCE

Negotible with 5-Ton Pierce Arrow Trucks

Based on the Formula: $$\frac{63000\times P\times x\times e}{n\times\frac{d}{2}\times W\left(\frac{20\,g+R}{2000}\right)}=1$$

P – Brake horsepower at speed (n) of motor.
n – r.p.m. of motor.
r – Total gear ratio between motor and wheels.
e – mechanical efficiency between motor and wheels.
d – wheel diameter in inches.
w – gross weight of loaded vehicle, { 5-ton 18,000 pounds. 2-ton 10,000 "
g – gradient per cent.
R – road resistance in pounds per short ton.

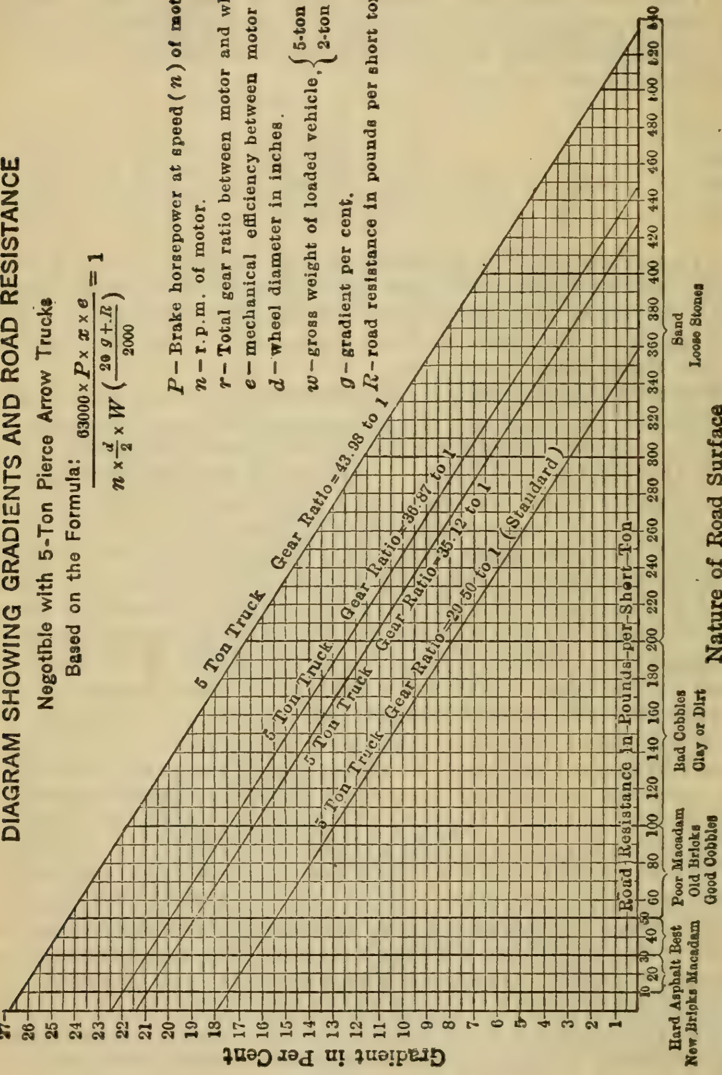


CHART A.

OPTIONAL GEARING ON FIVE-TON MODEL

The first option is our standard gearing and will be supplied on all orders .nless otherwise specified. This gearing should be used where the truck is o traverse good hard roads at all times, and where the grades do not ex- eed 10%.

The second option gives great pulling power on the low speeds, and the tandard speed of 14 miles per hour on high gear. This gearing should be sed only where the truck has to pull through a very short portion of poor oad and the great majority of the running is done on direct drive. This ption is popular with contractors, etc.

The third option is especially suited for districts where by nature of roads r traffic conditions a high speed is undesirable, or in hilly country, where the oad surfaces are good. This gearing is standard equipment on the long vheel base model.

The fourth option should only be used where the road surfaces are ex- eedingly poor, and the country very hilly. We do not advise using this earing except in extreme cases.

as discussed later. It should, however, be borne in mind that, : trucks are operating regularly over a stated route, special gear ratic can be and are used to meet the existing grades (see Chart A, note p. 95). Gear shift, therefore, plays a minor part in grade selection.

Effect of Grade on Load.—Modern single-unit trucks or passenge cars have enough power to carry their full-weight load up an grade within the limits of standard highway design. Limitation c load has no effect on maximum grade design from the standpoir of single-unit motors.

Long trailer train loads are limited by maximum grades an demand low maximum grades. It should, however, be remembere that this type of haulage is slow, clutters up the highway, is dangeı ous to ordinary traffic, and only in rare instances for special road should it be permitted or grades designed for such haulage.

Chart *A* shows the ability of Pierce Arrow trucks to pull on diffeı ent kinds of roads and different grades.

Effect of Grades on Motor Operation Cost.—For a detailed discus sion of this complicated subject the reader is referred to standar highway books and government reports on road economics.[1] Th application of Tables 5 and 6 (p. 12) will give a good basis for th approximate solution of special cases desired and the followin short discussion gives summarized general conclusions.

As a preamble to any discussion of the effect of motor operatio cost on the design of grades, it is just as well to bear in mind tha the American high-powered passenger car is not designed primaril for low fuel cost per ton mile; that the average owner does nc attempt to reduce his fuel costs to a minimum by careful attentio to mechanical adjustments; and that more gasoline and oil aı wasted yearly through sheer individual carelessness and ignoranc than could possibly be saved by the greatest refinements of desigı

The cost of a business trip by motor is reckoned as the sum of th cost of operating the vehicle and the time consumed in making th trip. The value of small-time increments gained by grade reduc tions is so small that for practical purposes it can be ignored in mos cases. The cost of motor operation includes gas, oil, tires, repairs and depreciation. The effect of grades on gas and oil consumptio can be figured with reasonable accuracy, and it has been found tha tires, repairs, and depreciation are almost directly proportioned t gas consumption.

Table 25 gives the relation between rolling resistance and ga consumption.

Table 26 gives the approximate relative cost of different items c operation for different types of road vehicles. Table 4 (p. 11 gives the approximate total cost of operation per mile.

From these or similar data it is simple to approximate the effec of grade on the cost of operation while climbing the grade.

The cost of operation downhill is more uncertain.

Table 27 page 100 gives an approximation of the costs of operatin up and down different grades.

[1] *Bull.* 69, Iowa State College. "Location, Grading and Drainage c Highways," McGraw-Hill Book Company, Inc. "The Construction o Roads and Pavements," McGraw-Hill Book Company, Inc.

Type and condition of roadway surface	Average values rolling plus air resistance				Relative fuel consumption with that on surface for which R = 30 lb. per ton taken as unity			
	Solid tires, 10 m.p.h.	Pneumatic tires, 15 m.p.h.	Pneumatic tires, 25 m.p.h.	Pneumatic tires, 35 m.p.h.	Solid tires, 10 m.p.h.	Pneumatic tires, 15 m.p.h.	Pneumatic tires, 25 m.p.h.	Pneumatic tires, 35 m.p.h.
Portland cement concrete—best, newly finished	30	22	27	35	1.00	0.89	0.96	1.07
Portland cement concrete—rough due to poor work	36	30	35	42	1.08	1.00	1.07	1.16
Portland cement concrete—average good condition	32	27	32	39	1.02	0.96	1.02	1.12
Asphaltic concrete, coarse-graded type, average yearly temperature—best	30	35	30	37	1.00	0.93	1.00	1.09
Asphaltic concrete, coarse-graded type, average yearly temperature—average	33	27	32	39	1.04	0.96	1.02	1.12
Sheet asphalt at average yearly temperature—best	28	23	28	35	0.97	0.91	0.97	1.07
Sheet asphalt at average yearly temperature—average	36	30	35	42	1.08	1.00	1.07	1.16
Bituminous filled brick—average—no filler on surface	30	26	31	38	1.00	0.95	1.01	1.11
Grout-filled brick—average	37	30	38	45	1.09	1.00	1.11	1.20
Wood block bare of filler—average uniform surface	35	30	34	40	1.07	1.00	1.05	1.13
Gravel—best clay bound	40	35	40	47	1.13	1.07	1.13	1.23
Gravel fair to poor—rough spots, some loose material	55	50	55	62	1.33	1.27	1.33	1.42
Gravel poorest condition—rough and many loose pieces	60	55	60	65	1.40	1.33	1.40	1.47
Gravel, Iowa yearly—average, approximated	50	45	50	57	1.27	1.20	1.27	1.36
Natural soil—good, well graded, and patrol maintained	45	35	40	47	1.20	1.07	1.13	1.23
Natural soil—soft (or slightly "spongy")	70	70	75	80	1.54	1.53	1.60	1.67
Natural soil—Iowa yearly average, approximated	55	45	50	58	1.33	1.20	1.27	1.37
Snow—2″ thick and well packed	55	50	70	..	1.33	1.27	1.53	
Snow—about 4″ thick, slightly packed	75	70	..	..	1.60	1.53		
Snow—about 4″ thick, slightly packed, chains on wheels	75	..	..	..	1.60			
Average for best paved surfaces—concrete, asphalt, brick and wood block	30	22	27	37	1.00	0.89	0.96	1.09
Average for partly worn pavements, *i.e.*, in fair average condition	35	30	35	42	1.07	1.00	1.07	1.16
Yearly average for best gravel of type used on trunk line	45	40	45	55	1.20	1.12	1.20	1.33
Yearly average for ordinary gravel found on secondary roads	55	50	55	65	1.33	1.27	1.33	1.47
Yearly average for second-class earth roads under good maintenance	65	60	63	75	1.47	1.40	1.44	1.60
Yearly average for best earth roads under heavy traffic and well maintained	55	50	53	65	1.33	1.27	1.31	1.47

[1] *Bull.* 69, Iowa State College.

As one-half of traffic is uphill and one-half is downhill on most roads, the final cost for any grade must be the average of these two values. Tables 5 and 6 (p. 12) were derived on this basis.

The detailed study of a large number of cases have led to the following general conclusions:

TABLE 25*A*.—RELATION BETWEEN FUEL CONSUMPTION AND TRACTIVE RESISTANCE[1]

Type	Source of data			Relative tractive resistance
	Ames	Canadian engineer	A. N. Johnson	
Good pavement	1.00	1.00	1.00	1.00
Macadam and bituminous macadam	....	1.23	1.24	1.20
Gravel	1.43	2.1	1.64	1.6
Earth	2.10	2.03	2.04	2.20

[1] "Rural Highway Pavements," McGraw-Hill Book Company, Inc.

TABLE 25*B*.—GAS CONSUMPTION ON DIFFERENT PAVEMENTS[1]

Type of pavement	Gallons per ton-mile	Miles per gallon, 2-ton truck
Earth (average conditions)	0.083	6.0
Gravel (average conditions)	0.059	8.5
Macadam (average conditions)	0.048	10.5
Rigid pavements (average conditions)	0.046	11.0

[1] "Rural Highway Pavements," McGraw-Hill Book Company, Inc.

TABLE 26*A*.—MOTOR TRUCKS. APPROXIMATE RELATION OF EACH ITEM OF COST TO THE COST OF GASOLINE[1]

Cost items	% of total	Ratio to fuel cost
Gasoline	12.9	1.00
Oil	1.9	0.12
Tires	9.2	0.71
Maintenance	12.7	0.99
Depreciation	14.3	1.11
License	1.3	0.10
Garage	3.7	0.29
Interest	3.8	0.30
Insurance	4.0	0.31
Supervision	6.7	0.52
Driver	29.5	2.29
Mileage items M	51.0	3.93
Time items T	49.0	3.81
Combined items	100.0	7.74

[1] *Bull.* 69, Iowa State College (1925).

TABLE 26*B*.—MOTOR BUSSES. APPROXIMATE RELATION OF EACH ITEM OF COST TO THE COST OF GASOLINE

Items	% of total	Ratio to fuel cost
Gasoline	14.8	1.00
Oil	1.8	0.12
Tires	11.2	0.75
Maintenance	15.6	1.06
Depreciation	13.9	0.93
Driver	26.4	1.78
All other items	16.3	1.09
Mileage items M	57.3	3.86
Time items T	42.7	2.87
Combined items	100.0	6.73

TABLE 26*C*.—APPROXIMATE RELATION OF EACH AUTOMOBILE COST ITEM TO THE COST OF GASOLINE (ORDINARY UTILITY AUTOMOBILE)

Items	% of total	Ratio to fuel cost
Gasoline	15.7	1.00
Oil	3.0	0.19
Tires	9.5	0.605
Maintenance	12.1	0.77
Depreciation	30.8	1.96
Interest	12.1	0.77
Insurance	3.0	0.19
Garage	8.1	0.52
License	5.7	0.36
Mileage items	71.1	4.53
Time items	28.9	1.84
Combined items	100.0	6.37

Summary of Motor Traffic Considerations.—From a practical standpoint, the following general conclusions seem sound:

1. The selection of maximum grade within the bounds of standard practice is not affected by the ability of single-unit motor vehicles to climb. The long trailer system demands low rates of ruling grade.

2. The selection of maximum grade up to 7% maximum is not affected by the factor of safe descent from the standpoint of single-unit motors, provided the alignment is nearly straight. 5% is desirable on curved alignment.

3. For a fixed rise and fall and distance a combination of different rates of grade has no appreciable effect on fuel consumption. The total cost of motor operation, including the time factor, however, is probably slightly less for a uniform grade. This effect is not, however, noticeable enough to reduce the steepest grade below a reasonable maximum and has no practical effect on the use of

Table 27.—Analysis of Relative Operating Cost of Average Motor Traffic for 1 Mile of Distance on Different Rates of Grade, Based on 11 cts. per Mile on a 1% Grade[1]

Distance factor, 2 cts. for 1% grade			Fuel factor, 3 cts. for 1% grade		Time factor, 6 cts. for 1% grade		Total operating cost, cents
Rate grade, per cent	Factor ratio for each rate of grade	Cost for each grade, cents	Factor ratio for each rate of grade	Cost for each grade, cents	Factor ratio	Cost for each grade, cents	
+10	1	2	4	12	4.0	24	38.0
+ 9	1	2	3⅔	11	3.6	21.6	34.6
+ 8	1	2	3⅓	10	3.2	19.2	31.2
+ 7	1	2	3.0	9	2.8	16.8	27.8
+ 6	1	2	2⅔	8	2.4	14.4	24.4
+ 5	1	2	2⅓	7	2.0	12.0	21.0
+ 4	1	2	2.0	6	1.6	9.6	17.6
+ 3	1	2	1⅔	5	1.3	7.8	14.8
+ 2	1	2	1⅓	4	1.1	6.6	12.6
+ 1	1	2	1.0	3	1.0	6	11.0
Level	1	2	0.9	2.7	1.0	6	10.7
− 1	1	2	0.8	2.4	1.0	6	10.4
− 2	1	2	0.6	1.8	1.0	6	9.8
− 3	1	2	0.4	1.2	1.0	6	9.2
− 4	1	2	0.2	0.6	1.0	6	8.6
− 5	1	2	0.1	0.3	1.0	6	8.3
− 6	1	2	0.1	0.3	1.2	7.2	9.5
− 7	1	2	0.1	0.3	1.4	8.4	10.7
− 8	1	2	0.1	0.3	1.6	9.6	11.9
− 9	1	2	0.1	0.3	1.8	10.8	13.1
−10	1	2	0.1	0.3	2.0	12.0	14.3

[1] "Location, Grading and Drainage of Highways," McGraw-Hill Book Company, Inc.

Notes.—1. If anything, the fuel factor between the grades of −3 and −10% is a trifle low.

2. The time factor between the rates of grade of −5 and −10% depends very largely on the alignment, the individual driver, and whether or not he is in the habit of driving on steep grades. It is probably about right for passenger cars but too high for truck operation and might be reduced to 1.5 at a −10% for truck traffic in hilly country.

3. The time factor on grades of +2 to +10% is too high for high-power touring cars, as on good alignment the normal speed is often not reduced at all up to 6%.

rolling grades on intermediate profile design, as the value of smoothing out minor grade irregularities becomes less as the rate of grade is reduced.

4. For a fixed rise and variable distance depending on the rate of grade the lower the rate of grade the higher the fuel consumption and operating cost. Under these conditions the grade should be kept to the steepest reasonable rate.

5. In the matter of convenience in driving it is desirable to avoid shifting gears. The limiting rates of grade at which the gears are shifted for the ordinary car on improved roads is about 6 and 10% for pleasure cars, and 5 and 8% for standard trucks. This, however, is subject to constant change and is not of much importance.

6. The value of distance saved can be closely approximated.

7. The value of rise saved cannot be closely figured, but it is certain that it has more money value on steep grades than on light grades.

8. In locating roads, distance can be balanced against rise, but it is not possible to analyze this closely, and, as a rule, distance should rarely be increased, particularly if good alignment is lost, unless it is necessary to get a reasonable maximum grade or unless a noticeable localized rise and fall can be eliminated by a short additional distance. (Use Table 6, p. 12, for comparison of this nature.)

9. Ruling grades need not be consistent in rate so far as ordinary motor traffic is concerned as they do not limit the load of single-unit hauling rigs. Ruling grades should be consistent if the trailer train system controls the design.

It can be seen that the requirements of ordinary motor traffic have less definite claims for consideration in reducing the rate of maximum grades than horse traffic, but have more claim than horse traffic in the matter of reducing distance and rise and fall on account of the large amounts of money annually spent on operation costs. Summarizing, it can be said that ordinary motor traffic warrants higher rates of maximum grades than horse traffic, but demands short distance and less rise and fall on steep grades. The reduction of rise and fall on light grades is of very little practical value. For certain special conditions where the trailer train must be considered, maximum grades may well be reduced below even the limits required for horse traffic.

Practical Considerations Governing Selection of Grade

Effect of Maintenance Cost on the Selection of Maximum Grades.—The maintenance of shoulders, ditches, and water-bound macadam, gravel, or natural-soil surfaces increases in cost rapidly on grades over 5%. From the standpoint of maintenance cost 5% is the logical maximum rate.

Effect of Safe Footing on Maximum Grade.—In the matter of safe team footing, it is possible to select some type of pavement which will satisfy this condition for any grade used, but a change in surfacing to meet this requirement is often omitted on account of expense and more often by careless design. Most of the rigid-pavement types give satisfactory footing up to 5%, which is the practical limit without special design. Bituminous macadams can, by variations in manipulation, be made suitable for grades up to 8%. Plain macadams give good footing for any grade, but are too expensive to maintain over 5%. From the standpoint of team footing, 5% has a distinct advantage on main roads where rigid types are desirable, and 7 or 8% is a reasonable limit on side roads where some form of macadam or gravel will probably be used. Team footing is, however, becoming less important as a deciding factor. Seven per cent is a reasonable maximum from the standpoint of safety of motor traffic, due to skidding on a smooth pavement when brakes are applied. The following table indicates current practice in the matter of maximum grades for different surfaces.

SURFACE MATERIAL

	%
Wooden block	2
Asphalt block	4
Brick (grout joints)	5
Brick (mastic joints)	8
Concrete[1]	5 to 7
Bituminous macadam with flush or squeegee coat	5
(In sandy country, 6% when coarse sand is sprinkled on surface.)	
Bituminous macadam without squeegee	8
Water-bound macadam	8
"Hillside" brick	12
Stone block with open joints	12

[1] Hard to construct on grades over 5%.

Effect of Farm Hauling on Maximum Grade.—From the stand point of accommodating ordinary farm team loads, 7% is the logica ruling rate. This is based on a load of 5000 lb. for farm hauling which includes wagon weight. The records of produce dealers i the eastern states show that the ordinary wagon weighs about 135 lb. and that 3500 lb. is a large net load. This load of 2.4 tons corre sponds with the maximum theoretical load for 7% hard-surface grade. Team loads of 6 tons would be very unusual, which mean that the ideal teaming grade of 2½% need not be considered excep in level country where it can be obtained without much extra cost

Effect of Construction Cost on Maximum Grade.—From th standpoint of construction cost 5 to 7% can generally be buil without excessive expenditure even in hilly country.

Maximum Grades in Present Use.—The maximum grades in pres ent use represent the best judgment of engineers from all over th world backed by practical experience and traffic tests of generations It is true that they are largely based on factors of horse traffic reasonable construction, and maintenance costs, but it is believe that these factors are still the most important deciding elements i the selection of maximum grade for most roads. Table 28 give the rates in common use and is probably the most reliable basi for design that can be used.

TABLE 28.—MAXIMUM GRADES IN FOREIGN COUNTRIES

Location	Mountainous districts, %	Hilly districts, %	Level districts, %
Prussia	5	4	2½
Hanover	4	3⅓	2½
Baden	8	6	5
Brunswick	5½	4	3
Holyrood Road in England	6	3½	

Military highway over the Alps, Italian side, 4½%; Swiss side, 6%.

Location	National roads, %	Departmental roads, %	Subordinate roads, %
France	3	4	6

MAXIMUM GRADES IN THE UNITED STATES

State	Main roads, %	Side roads, %	Unusual cases, %
New York	5 and 7	7 and 8	11
Massachusetts	5	7	
Connecticut	5		
New Jersey	5	6 and 7	9
Michigan	6		
Missouri	5 and 6		
Washington	5	5	
Illinois	6	..	9

UNITED STATES NATIONAL FOREST ROADS (MOUNTAINOUS DISTRICTS)

First-class roads............long grades 5%, short grades 7%
Second-class roads...........long grades 7%, short grades 10%
Third-class roads............long grades 10%, short grades 12%
State of Colorado (main mountain roads)....................6%

Effect of Maximum Grade on Cost.—Money spent on the reduction of maximum grade is never wasted unless distance is increased for a fixed rise by a grade lower than a reasonable maximum. It is not good policy to spend large sums to reduce below 5% in hilly country or 2% in level country, even where distance is not increased. The effect on cost of the selection of a 5 in place of a 6% or a 6 in place of a 7% depends largely on the method of construction that must be used. Where locations are fixed by well-established right of ways and permanent structures and the cost of new right of way is very high, grades are generally reduced by cut and fill. Under these conditions the effect of the selection of rate is very marked and no general relation can be established, as each case is a law unto itself.

Unfortunately, many of the roads in the older states were not laid out on natural engineering locations, and grade improvements are expensive either on account of excessive cut and fill or the high cost of new right of way on a better location. In mountain road or ordinary locations in newly settled districts, the question of right of way rarely handicaps the design and easy grades are obtained at moderate cost by natural locations which avoid steep adverse grades by going around a hill or develop moderate grades on a long climb

by a longer distance. In climbing on a side-hill location the road section is generally what is known as a balanced section, that is the cut just makes the fill by side displacement. The amount of excavation per mile is not affected by the rate of grade, but sometimes the length of road is affected.

Generalizing, it can be said that the effect of grade reduction on cost is not so marked as for cut and fill methods and that, roughly the relation of cost to grade depends on the length, which is often inversely proportional to the rate; that is, where cut and fill is used a 5% grade might easily cost three or four times as much as a 6% grade, but where side-hill location is possible, a 5% would rarely cost more than six fifths as much as a 6%. This is, of course, affected

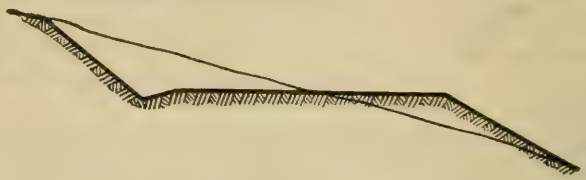


FIG. 11.—Balanced sidehill section.

by all sorts of local conditions and may not apply at all, but is true by and large and serves to illustrate the relation of rate to cost. To illustrate (Fig. 12): If the difference in elevation between *A* and *B* is 1000′ a 6% grade would require approximately $3\frac{1}{3}$ miles of length and a 5% grade 4 miles to make the ascent. If the direct distance between *A* and *B* is less than $3\frac{1}{3}$ miles the lengths of the two lines will be approximately as given. If the distance from *A* to *B* is more than 4 miles there would be little difference in the length, as it would merely mean that the 5% started to climb sooner than the 6%

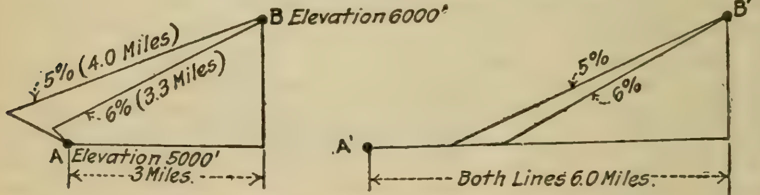


FIG. 12.

Under most conditions the cost would be more affected by the character of the excavation on the different locations and by the number of switchbacks required for the smaller rate. The difference in cost due to the difference in rate of maximum grade in mountain location does not often warrant the adoption of excessive grades.

Recommended General Practice Maximum Grades.—From the standpoint of horse traffic, single-unit motor traffic or trucks with one trailer, safe footing, and economy of construction and maintenance the following recommended rates of maximum grades will

ive moderately good satisfaction. In unusual cases the possibility f the extensive use of long trailer trains would tend to reduce hese recommended rates, but the author wishes to emphasize the pinion that very few roads need be designed at this time primarily or long trailer trains. The following rates are satisfactory for the rdinary motor equipment used by the great majority of road users nd additional expenditure would not be warranted for the benefit f a few men. For the effect of dangerous alignment on maximum rade see page 117.

Main Commercial Roads in Flat Country.—Long 2% ruling rades are desirable, but they do not justify much additional contruction cost. Any long ruling grade up to 5% will probably be atisfactory. Short 6% are not inconsistent. A large volume of auling by trailer trains might warrant reductions below usual ractice, provided the interests operating such haulage paid the ncreased cost of construction.

Main Commercial Roads in Hilly Country (Well-settled Districts). ong 5% ruling grades are desirable and justify considerable xpenditure, provided they do not increase the total distance. Seven er cent grades are probably justified to prevent increase in distance or a fixed rise. Long 6% grades are fairly satisfactory, but, as a ule, if 5% cannot be reasonably obtained it is just as well to jump o 7%. Short 7 or 8% grades are not inconsistent in connection vith long 5 and 6% grades, provided the element of safe team footng is considered.

Main Roads Pioneer Districts.—Long 5% grades are very desirble, provided they do not increase the total distance, particularly the road is a natural-soil road and considerable horse traffic preails. Any long grade up to 7% is fairly satisfactory. Short 7 and 0% grades are not inconsistent except for trailer trains. Grades igher than 7% are not, however, in much favor on account of anger and high maintenance cost.

Side Agricultural Roads or Unimportant Pioneer Roads.—Any ong grade up to 7% is satisfactory. Short 10% grades are consistnt in connection with a 7% ruling, provided the element of safe ooting is considered. Grades steeper than 7%, however, have a igh maintenance cost and are dangerous even with good alignment.

Scenic Roads.—Long 6% grades are convenient on account of reventing gear shifts. Ten per cent is not unreasonable for such oads, except that on this grade the alignment should be easy, as ater discussed, the maintenance cost is high, and considerable anger is added for grades over 7%.

Effect of Alignment.—Sharp curves affect steep grades, as taken p under the subject of Alignment (p. 117).

Unusually High Rates of Grade.—Grades as high as 11% have een constructed on state-improved roads in New York and as high s 9% in New Jersey and Illinois, but the general opinion of the epartments under which these grades were built is that they would ot again use such a high rate except in villages where any material hange in street elevation would damage valuable properties. utside of corporations it is bad practice to use long grades of reater rate than 7%, for if any road is of sufficient importance to

warrant engineering plans for the future it is certainly of sufficient importance to warrant a reduction in grade to a reasonable rate.

Consistent Maximum Grades.—The design should be consistent if horse traffic is considered. Take, for example, a road between two shipping points. It is first necessary to determine the portion tributary to each terminal and then the practical grades on all the hills on each portion in order to decide what consistent ruling grade can be adopted without excessive cost. There is no object in reducing a hill from 7 to 5%, provided the total rise remains fixed with a large expenditure if near the terminal there is a grade that cannot be reduced below 7%. It should be borne in mind, however, that the nearer the shipping or market point is approached the more traffic the road will have, and if the hills are naturally flatter the ruling grade should be reduced. The direction of heavy traffic on each hill should be determined and considered. Ordinary motor traffic does not require consistent maximum grades, but the trailer train method does require them. Considerable expenditure is justified to obtain consistent grades for the benefit of team hauling on local service roads.

Intermediate Grades.—Intermediate grades include all rates between the maximum and minimum grades for the particular job in question. They afford the greatest chance for reasonable economy of earthwork of any part of the grading design and usually receive the least attention. From the standpoint of traffic they have practically no effect on travel cost or convenience on local service roads and only a slight effect on commercial roads. Economic analyses of relative value and relative grading costs show that it rarely pays to reduce intermediate grades below their natural rate (see Table 2, p. 6). Their proper use, however, controls the convenience and suitability of the road to abutting property and controlling conditions. In laying a profile grade the controlling points must first be considered; these are high-water levels of flood areas, elevations of existing bridges, railroad crossings, all points where deep cuts or high fills would damage the approaches to valuable property, connections with other highways, portions of the road previously improved, and, in villages, the elevation that will permit future widening and curbing that will fit the case.

Current practice handles most of these controlling features well with the exception of grades through villages, which are almost without exception too high for future widening and curb finish. Designers are cautioned to use city-street methods and to make the elevation the same as if a full-width curbed pavement was being designed.

Effect of Intermediate Grades on Cost.—All of these controlling points must be satisfied, but they usually affect only a small percentage of the length of any improvement and on the greater portion of the road the most economical elevation and any intermediate grade can be used. A grade so established that the cut in every cross-section would just make the fill at that point would result in the least possible excavation and the cheapest kind of grading methods. This condition can never be realized, but the nearer it is approximated the nearer the most economical grading design is

approached. Where intermediate grades are applicable, there is no restriction on any combination of rates, as they have no effect on traffic-loads and very little effect on motor operation cost, and by an intelligent selection the ideal solution can be closely approximated. The cheapest and most satisfactory profile can be obtained by the use of the "rolling grade." By this is meant a profile made up of a combination of simple, compound, or reverse vertical curves, connected by tangent grades only when the tangent grade is the most economical or is necessary to prevent a series of short humps and hollows. Long, straight grades are not required, a mistake easily made by engineers trained in railroad work. Short grades are not objectionable and reverse vertical curves ride easily if well built. The rolling grade is also more pleasing in appearance than a straight profile if not carried to extremes. The detail methods of laying such a grade are described in Chap. XIV (p. 963). It appears

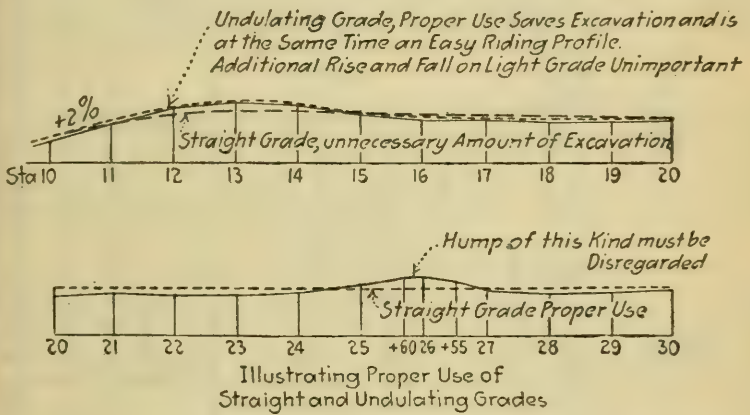


FIG. 13.—Proper and improper use of "rolling" grade.

that there is too much tendency to cut the top of each knoll and fill each hollow, for very little practical advantage results from reducing a natural 4% grade to 3.5% or a 3.5% natural grade to a 3% if the ruling grade is 5% and the rise remains fixed. See Table 2, p. 6 for the formulated conclusion in regard to reduction of intermediate grades and page 56 for economic discussion.

The importance of avoiding this tendency cannot be overestimated, as the plans of about 2000 miles of road, constructed in the last 10 years, which the writer has looked over in this connection show a needless expenditure of at least a million dollars for grading which has no practical value whatever. This element of costly design in current practice is probably due to the fact that the savings are not spectacular at any one place, but if the principle is consistently used the total result is spectacular.

It is also undoubtedly true that the previous railroad training of many road engineers has had a detrimental effect on intermediate profile design. From the standpoint of highway design, railroad practice overemphasizes the elimination of minor rise and fall on

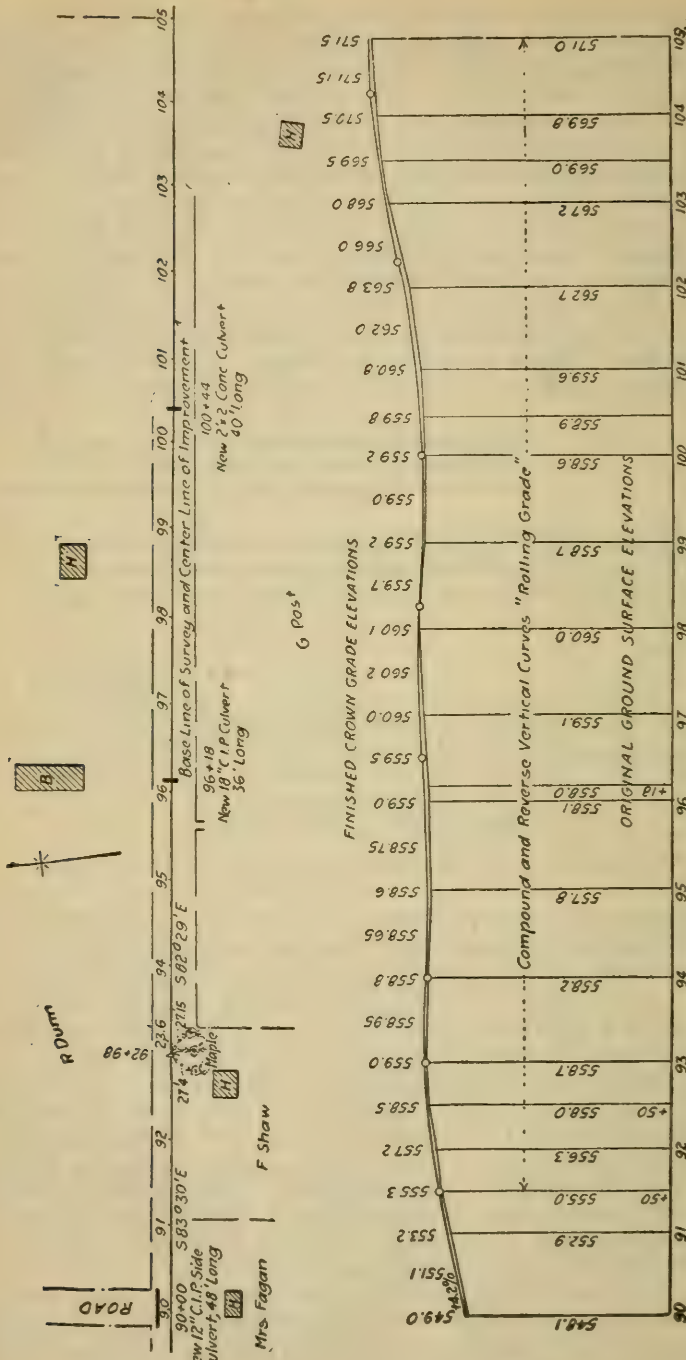


FIG. 14.—Typical example good use of "rolling" grade state road construction.

light grades. The author has personally applied the "rolling-grade" principle on construction work for the last 15 years and has found that the saving averaged about $500 per mile (using the 1926 scale of prices these savings would have averaged $1000 per mile). A systematic grade-line design will also often change the method of grading as well as reduce the yardage. To illustrate, the Heber Fruitland Road in Utah will be cited. The original design used long, straight railroad grades which required wagon haul; the redesign used a rolling grade which not only reduced the amount of excavation by about 30% but also practically eliminated wagon haul for most of the work and made it possible to handle the dirt with slip scrapers and road machine blade scrapers. This reduced the cost per cubic yard about 25%. The quantity reductions plus the unit-cost reductions amounted to approximately 50%.

In order to strengthen the force of the argument for "rolling grades" the following statement by G. R. Harr, Office Engineer of the Indiana Highway Commission, is inserted. The work to which he refers was done under the direction of H. K. Bishop, Chief Engineer.

"When we started here last May a year ago we had some plans previously prepared that had long, straight tangent railroad grades. We revised these plans using rolling grades having long and short vertical curves. In so doing we reduced the excavation very materially.

"From what I remember of the projects and the work on the same we saved from about 500 up to 4000 yd. to the mile. On one project the total excavation was cut practically in half."

The Effect of Arbitrary Profile Limitations on Cost.—A common grade-line limitation calls for tangent grades drawn to intersection with simple vertical curves easing off the apex and insists on 100′ of tangent grade between the ends of these vertical curves. This sounds scientific but has no practical value and is cited to illustrate the danger of ill-considered limitations. A specification of this kind often increases the grading by from 500 to 1000 cu. yd. per mile, an example of which is given below.

PITTSFORD NORTH HENRIETTA ROAD IN NEW YORK STATE
Length 2.67 miles

Original Design	Revised Design
Maximum grade, 5%.	Maximum grade, 5%.
Profile, straight grades with 100′ of tangent between vertical curves.	Profile, rolling grade.
Original amount excavation, 11,450 cu. yd.	Revised amount 9300 cu. yd.

(A saving of 800 yd. per mile.)

In conclusion, it may be said that the matter of intermediate grades needs more care than it often receives.

MINIMUM GRADES

Hard-surfaced Pavements.—Many road books claim that level grades should not be used because of the liability of water standing

in ruts, and that a certain minimum grade should be adopted that will insure their longitudinal drainage. Baker states, in his "Roads and Pavements," that for macadam roads English engineers use a minimum grade of 1.5%, French engineers 0.8%, and that the American practice favors 0.5%. This means that:

For a 1.5% grade the fall would be $\frac{1}{5}''$ per foot.

For a 0.8% grade the fall would be $\frac{1}{10}''$ per foot.

For a 0.5% grade the fall would be $\frac{1}{16}''$ per foot.

The flattest crown that is ordinarily used even on bituminous macadam is $\frac{3}{8}''$ per foot, or twice as much as the greatest longitudinal fall in the above list. For long ruts the longitudinal grade is, of course, effective, but the patrol system of maintenance is supposed to prevent their formation and for short, small depressions the crown slope must furnish the drainage. There seems to be no reason why level grades should not be used on hard-surfaced roads; on such stretches the crown can be increased slightly to insure transverse drainage and the ditches given a minimum longitudinal fall of 0.2 to 0.5′ per 100′ depending on the soil to insure the longitudinal drainage of the surface water.

Earth Roads.—On earth or gravel roads attention should be given to minimum grades, as for these types they have some value, but not enough to warrant much expenditure.

It is advisable to use a 0.4 to 0.5% grade where much snow or rain occurs, but in the arid regions no minimum restriction should be specified.

ADVERSE GRADES

Adverse grades are defined as grades contrary to the general rise and fall of the road between terminals or controlling points. It is important to avoid them on mountain-road locations where the prime object is to gain elevation or on main commercial roads where the factor of rise and fall has considerable value. They are not a serious drawback for the usual road and cannot be avoided in ordinary rolling topography. This is so self-evident that it hardly seems necessary to state it. There is no serious objection to short adverse grades even on a long climb, if by their use the alignment can be bettered and excavation saved in crossing a small gully. There is no objection to adverse grades of 2% or less on any road. The main objection to long adverse grades is that they introduce considerable additional rise and fall which could be avoided by a better engineering location. This point is generally considered in the selection of the general route and is covered by the comparison of routes in the preliminary investigation.

VERTICAL CURVES

Vertical curves between tangent rates of grade add to the safety, convenience, and appearance of the highway. Vertical curves, as a rule, are picked out to fit the natural profile and in easy-rolling topography this method of selection need not, as a rule, be modified for any other consideration. There are cases, however, where the length of the vertical curve at the summit of a hill controls the

length of sight ahead, and under these conditions certain minimum lengths are stipulated. A reasonable basis for decision in these cases appears to be founded on clear sight ahead at all times of 350′ for main commercial special-service roads and 250′ for local service roads except in mountainous regions where the sight distance requirement cannot be reasonably obtained. On this basis the following table is compiled, assuming that the line of sight is 5.5′ above the ground at the two ends and tangent to the vertical curve (see diagram for line of sight 5′ above ground at ends).

Table 29.—Based on a Line of Sight 5′ 6″ above the Ground at Both Ends

Algebraic difference in rates of grade, %	Minimum length of vertical curve in feet for a sight distance of 250′	Minimum length of vertical curve in feet for a sight distance of 350′
6	...	...
8	...	150
10	50	250
12	135	330
14	190	400
16	225	450

As a matter of fact, merely on account of appearance and convenience in motor operation to prevent disagreeable checking in speed at the foot of hills, it is not wise to use a vertical curve less than 100′ long between grades having an algebraic difference in rate of 5% or less. Vertical curves are generally used between all grades having an algebraic difference of over one-half of 1%.

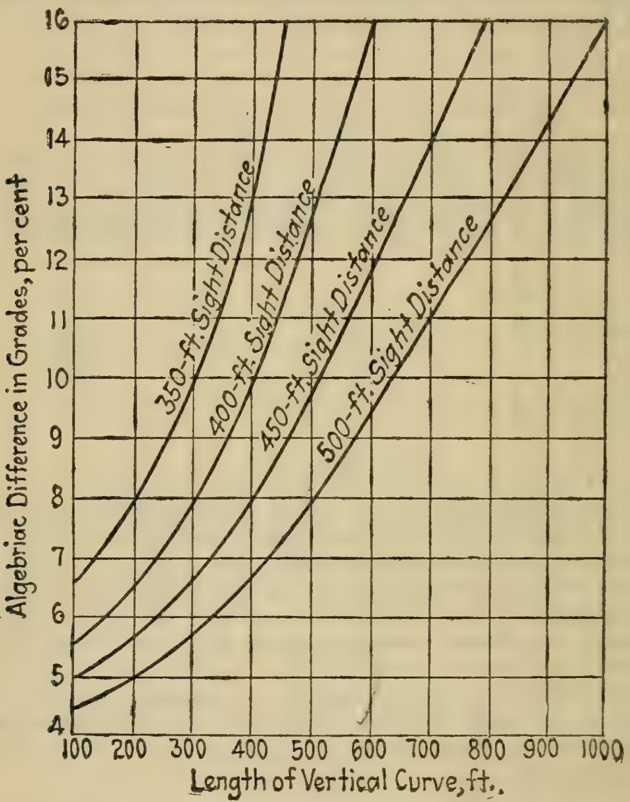
Minimum length of vertical curves from the standpoints of convenience, appearance, and sight distance can be assumed roughly as follows. There is no limitation on maximum length except that the curve should fit the profile without excessive grading. Vertical curves should be made as easy as possible without running up cost needlessly.

Table 30.—Recommended Minimum Lengths of Vertical Curves between Tangent Grades

Algebraic difference in rates of tangent grades, %	Minimum length of vertical curves on local service roads, feet	Minimum length of vertical curves on special-service commercial roads, feet
5 or less	100	100–150
8	150	200
10	200	300
12	250	400
14	270	450
16	300	

Summary of Grades.—The discussion of economic grading design may be summarized as follows:

The road value of reasonable maximum grades and a minimum amount of rise and fall on steep grades cannot be overestimated. Any expenditure on these features is justified so long as it is consistent with the theory of cheap operation. The use of properly proportioned short maximum grades in connection with long ruling grades is a source of justifiable economy and works no hardship except for long trailer trains. The use of the highest reasonable maximum to shorten distance for a fixed rise results in considerable construction saving in many cases and is justified on the score of reducing motor operation costs. Distance should never be increased for a fixed rise to reduce grades below a reasonable maximum.



Required length of vertical curves for different sight distances U. S. Bureau Public Roads Standard. (Based on line of sight 5 ft. above ground at both ends and tangent to road surface at middle.)

Minimum center-line grades have no road value on hard-surfaced roads and only a slight value on earth roads. Minimum ditch grades are important.

The traffic value of intermediate grades is negligible on local ervice roads and only of minor importance on special-service roads. ntermediate grade-line design has a large effect on grading cost nd is entitled to very careful consideration. The most common aults of the ordinary treatment of these grades are the needless eduction of light natural grades and the use of long, straight raiload rates of grade. There is no practical advantage whatever from he use of long, uniform light rates of grade where the total rise and all is not changed and very little real value is accomplished by the eduction of minor rise and fall occurring on light natural grades.

ALIGNMENT

Alignment affects the safety, speed, ease, and hauling power of raffic and the cost of road construction. Highway location is ontrolled at many places by the effect of curvature on maximum rade and the effect of alignment on construction cost. Sharp lignment modifies the allowable rate of grade, the width of pavenent, width and shape of section, and increases the need for subtantial safety devices, such as retaining wall or concrete or steel able guard rail. At this point in the discussion it is necessary to onsider only the factors in connection with alignment which would aturally control the field survey location, namely, the effect of lignment on grade, cost of construction, and safe sight distance or traffic. The effect of alignment on banking and widening pavenents on curves and on the design of guard rail, etc. will be taken ıp in Chap. III.

In well-settled communities alignment is practically controlled y the existing road right of ways except where short relocations vill materially reduce distance, needless rise, extreme grade, or langer to traffic. In sparsely settled communities alignment is not andicapped by right-of-way difficulties. As a general proposition, langerous or crooked alignment should not be introduced to reduce rades below the maximum. If it is necessary in order to get the naximum grade or to keep the construction cost within reason, well nd good. By this is meant that a straight road on a 5 or 7% grade s generally more satisfactory than the same road on a 3 or 5% rade with a dangerous turn. If the lower grade can be obtained vithout dangerous alignment and without increasing distance, all vell and good. A reasonable maximum grade, however, should ot be sacrificed on a side-hill location for better alignment, as uture improvements, grading, etc. can reduce alignment danger nuch more easily than it can reduce grade by an entire relocation, nd the danger at a few sharp bends on a long climb having nornally safe alignment can be reduced by flattening the grade at the langer point; that is, the necessity of one or two sharp switchback urns to get a long reasonable maximum rate would not warrant n increase in grade above the reasonable maximum in order to liminate these turns. Short maximums in connection with long ower maximums are warranted to improve alignment. The general principles of alignment are given on pp. 82 and 120.

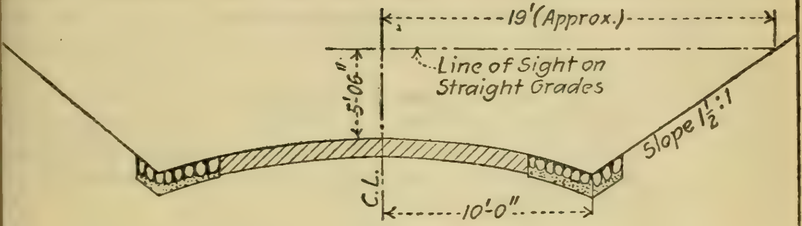
Dangerous Alignment.—Danger due to alignment is largely a relative matter. If a road is uniformily crooked, few accidents occur. The worst condition for accidents is a single sharp curve on a road otherwise straight. If an extremely sharp curve is necessary, the danger can be greatly reduced by gradually increasing curvature and reducing sight distance for other curves as the danger point is approached. This method has been successfully used in western New York in approaching difficult hair-pin turns.

The state of Maryland has kept track of auto smashups and reports more accidents on straight alignment than on curves and more accidents on sparsely traveled sections of main roads than in the congested districts near cities. This is, apparently, due to the temptation to "step on it" under apparently favorable conditions.

Sharp curves are not particularly dangerous for slow horse traffic but they are extremely dangerous for high-speed motor traffic, particularly on through roads used by drivers not familiar with the locality. It is, of course, impossible to protect traffic from the carelessness of speed maniacs, but the danger of collisions can be materially reduced by alignment which permits the driver to see ahead a reasonable distance at all times. Cars driven at high speed are liable to leave the road on almost any curve, as observation has shown that about as many cars go off moderately easy curves up to 500′ radius as they do on very sharp curves, on account of the tendency to take the easier curves at excessively high speed. The danger of collision is less, however, as it gives the other man a chance to protect himself. We are not particularly grieved if a fool does commit suicide. A touring speed of 25 to 35 m.p.h. is reasonable for main-road travel in ordinary rolling topography. Tests on the braking power of automobiles show that a passenger car traveling 20 m.p.h. can be stopped in 40′, and one going 40 m.p.h. in 140′ by the use of the emergency brake. As a matter of fact, brakes are not always efficient, a driver requires a little time to realize that danger exists after first seeing the approaching car, so that the determination of safe sight distance is largely a matter of judgment.

Sight Distance.—The authors have written to a large number of automobile clubs over the country and, in the main, they agree on 250 to 300′ as the minimum safe sight distance ahead at all times. The shorter distance is used on local service roads where most of the drivers are familiar with the road and the longer distance for main routes carrying foreign traffic not familiar with the existing alignment. This corresponds with the practice of various highway departments. Roads built with this limitation seem satisfactory to traffic. A sight distance of this kind does not necessarily depend on alignment unless the curve is in cut. Alignment is not affected by sight distance unless the curve is in cut or along a side hill where the cut slope is on the inside of the curve or where buildings or trees occur along the right-of-way line. The smallest radius of curvature that is permissible to give a certain sight distance depends on the width of the road section in cut and can be easily worked out diagrammatically for any special case. To give an idea of the various minimum alignment radii required for the different sight distances for curves in cut, Table 31, is inserted.

150' Sight Distance A	150' Sight Distance B	200' Sight Distance A	200' Sight Distance B	250' Sight Distance A	250' Sight Distance B	300' Sight Distance A	300' Sight Distance B	350' Sight Distance A	350' Sight Distance B	400' Sight Distance A	400' Sight Distance B
			Values given below are the radii in feet								
158	286	272	505	420	786	600	1130	815	1536	1062	2005



Contracted Section in Deep Cuts.
This is the Section on which this Table is Based

TABLE NO 31

This table is compiled for the minimum width section used in Vew York State in 1919. Similar tables can be prepared for the tandard sections in use in any particular locality. Column A in ach case applies where the curve is on a straight grade and the line f sight is 5′ 6″ above the crown grade of the road. Column B in ach case applies where the curve is at a change of grade and the ine of sight is just above the ground at the ditch line.

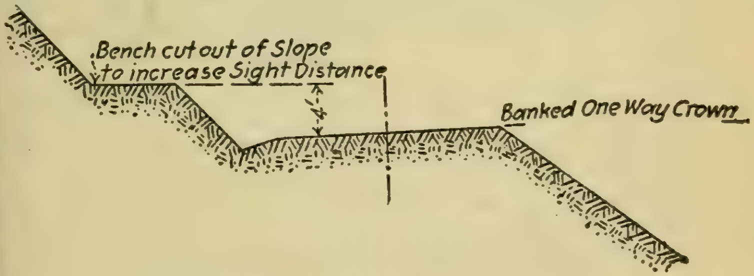


FIG. 15.—"Daylighting" a curve.

The radius for a specified sight distance can be figured by the ormula

$$R = \frac{M}{2} + \frac{C^2}{8M},$$

here R = the road center line radius, in feet.

M = the distance in feet off the center line of the road where the line of sight comes tangent to the cut slope or any other obstruction.

C = required length of sight distance, in feet.

The sight distance for any specified alignment radius and standrd section can be increased by "daylighting" the curve as shown

in Fig. 15. This method has the distinct advantage of cheapening the grading cost and it also gives the driver a chance to see ahead even if he hugs the inside of the curve.

Current Practice, Minimum Curvature.—Sharp curves on steep grades or at the foot of such grades are not safe. Good practice calls for a minimum radius of 400′ to 800′ for these cases in ordinary topography. Right-angle turns even on level stretches are an abomination to the Lord. A minimum radius of 200′ for such cases increases the convenience of the road and is greatly appreciated by the road users.

France and Austria have used minimum radii of 100 to 165′ on main roads and as low as 50′ radii on district roads, but these limits are hardly suitable for fast traffic. The use of tractor trailer trains, four- or six-horse teams, or the hauling of long timber sometimes limits the radius of a curve.

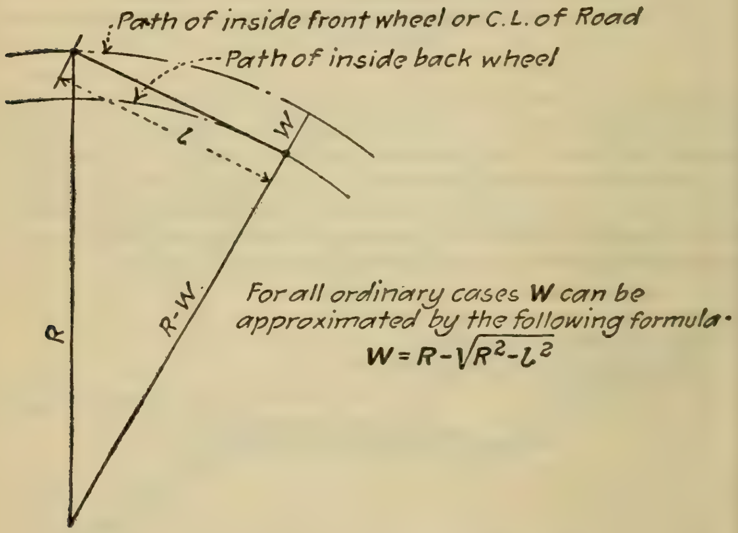


FIG. 16.—Rear wheel encroachment.

Rear-wheel Encroachment.—Under these conditions it is desirable to widen the section of the inside of the curve to provide clearance for the last wagon or the back wheels of a long rig as they work in towards the bank. To approximate roughly the distance that the last wheel works inside of the front guide wheel track, it will be assumed that the rig has a stiff connection between the front and rear axles. This will give a result on the safe side, as for a loosely coupled train or a special swinging rear axle much sharper corners can be turned.

TABLE 32.—TABLE OF APPROXIMATE ENCROACHMENT OF REAR WHEEL INSIDE OF PATH OF FRONT WHEEL FOR DIFFERENT LENGTHS OF RIG AND DIFFERENT RADII OF ROAD CENTER LINE, ASSUMING THAT THE CENTRAL ANGLE OF THE CURVE IS LARGE ENOUGH TO PRODUCE THE FULL ENCROACHMENT. THIS GENERALLY OCCURS WHEN THE CURVE IS TWO OR THREE TIMES AS LONG AS THE LENGTH OF THE RIG

Approximate radius of road center line, in feet	Length of rig between front and rear axle, in feet				
	10	20	30	40	50
	The values given below are the approximate distances in feet that the rear wheel runs inside of the front wheels				
40	1.3	5.4	....	....	....
50	1.0	4.2	10.0	....	....
60	0.8	3.4	8.0	15.3	....
70	0.7	2.9	6.8	12.6	21.0
80	0.7	2.5	5.8	10.7	17.5
100	0.5	2.0	4.6	8.4	13.4
120	0.4	1.7	3.8	6.9	10.9
150	0.3	1.3	3.0	5.4	8.6
200	0.2	1.0	2.3	4.0	6.4
300	0.2	0.7	1.5	2.7	4.2
400	0.1	0.5	1.1	2.0	3.1

NOTE.—According to Droune, the first pair of horses will occupy about 13′ ahead of the wagon and each additional pair 10′ more each. Wagons range in length from about 10′ for the bottom-dump type to 50′ for trucks hauling timbers. The ordinary commercial 5-ton truck has a wheel base of 14 to 17′. Recent regulations limit the length from 20 to 30′ overall, and the total length of trailer trains to 90′.

Mountain-road Alignment.—In mountain-road location it is generally impossible to provide a safe sight distance except for main routes as it would be prohibitive in cost on local roads. For such conditions considerable must be left to the care of the driver and the limitations of alignment are based more on the cost of construction than on the safety of traffic. Where long timbers are hauled over the road the foregoing table indicates the extra width or radius required.

Effect of Alignment on Grade.—On sharp curves it is desirable for the driver to have first-class control on the score of safety. An extremely sharp curve with a large central angle also reduces the hauling capacity of a six-horse team by from 20 to 40%. Considering both safety and team hauling, it is therefore desirable to reduce ruling grades on sharp curves. These considerations have no practical value on mountain roads for curves having radii greater than 100′, but on sharper curves good practice, recognizes this principle. Ordinary design uses radii of from 40 to 80′ on difficult switchback turns. For a 40′ radius the grade should not exceed 3% and for an 80′ radius 4% is a reasonable maximum. For high-class roads in well-settled districts at points where the sight distance is

less than 350′ for commercial roads or 250′ for secondary state routes or local service roads, the grade should not exceed 3%. On high-class roads where the sight distance does not govern, the following simple rule has served satisfactorily.

Compensating Grades for Curvature (High-class Roads).—A simple rule for compensation of maximum grades on steep curves is to reduce grade around curve enough to permit future alignment straightening up to the highest standards of alignment without increasing the future rate of grade for the improved future location beyond a reasonable maximum. The authors compensate curves sharper than the permissible maximum for the class of road in question on the basis of first-class future alignment with reasonable maximum future gradient. This rule automatically takes care of the difference in central angle, which is an important factor.

Effect of Alignment on Motor Operation Costs.—Dangerous sharp alignment increases motor operation costs. It decreases normal speed and results in the needless use of second- or low-gear climbing and excessive braking on down grades. This action occurs,

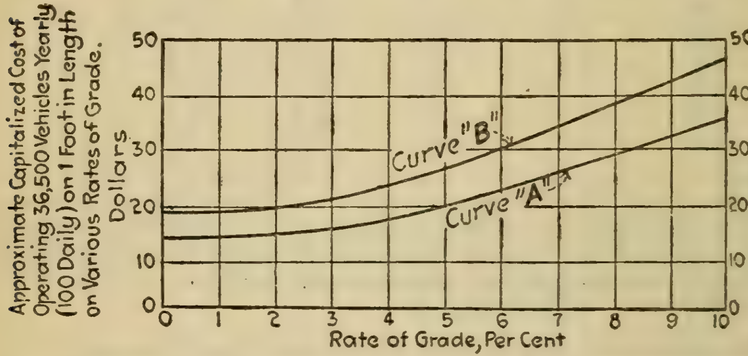


FIG. 17.—Graph illustrating approximate effect of dangerous alignment on motor operation cost (time factor included). Curve *A* safe alignment (based on Table 5, column 1, p. 12), curve *B* dangerous alignment (operation factors, modified for sharp alignment).

however, only on a very small percentage of the distance on a well-designed road, *viz.*, at the danger points; that is, if the alignment is safe for traffic it does not affect the operating cost. If it is dangerous for traffic it does affect the operating cost. As real danger is a more vital matter in the design than cost of operation, alignment design is controlled by the factor of safety and not by considerations of operating cost; that is, danger will be eliminated if it is possible to do so and no consideration of cheaper operation will improve the alignment if the consideration of danger had not been sufficient to warrant it.

While there are no good data on the effect of alignment on operating cost, there is sufficient general data to warrant stating with reasonable assurance that, if the radii of curvature are not sharper than from 250 to 300′ on the level or less than 400 to 600′ on grades

and the sight distance is not less than 250′, reasonable speeds need not be reduced on account of alignment and motor operating costs are not materially affected. For sharper curvature and shorter sight distance the cost of operation is probably increased. How much is not known, but purely as a matter of academic interest the factors used in compiling Table 5 (p. 12), for usual alignment, have been modified to conform with certain observed speeds on dangerous alignment. Figure 17 page 118 shows the result.

Curve *A* represents safe alignment, curve *B* represents dangerous alignment.

The general conclusion to be drawn is that motor operation is cheaper on good alignment and that, if alignment can be made safe by steepening the rate of grade, a slight increase in rate will not add to motor operation costs over that required for the lower rate and poor alignment.

In conclusion, it may be said from the standpoints both of safety and of operating costs that it is desirable to design special-service commercial roads for a sight distance of about 350′ and local service or secondary state routes for about 250′. Considerable expenditure is justified to obtain this requirement, but large additional cost in order to increase further the sight distance is wasteful and poor engineering, particularly on roads of secondary importance. This caution is not a needless one, as designers often excuse excessive profile and grading on the score that it increased the sight distance beyond the 350′ limit. This limit is not necessarily proper or liberal enough for all conditions, but it seems good sense to arrive at some limit suitable for the road in question and then to eliminate additional expenditure for an additional sight distance which may be fine if it can be afforded, but which is really not necessary. The tendency of almost all departments working with large appropriations is gradually to increase the fancy extras which may not amount to much for one case but which grow in number like a snowball until it is wondered why the cost of roads is going up and the mileage for appropriations coming down.

Effect of Alignment on Construction Cost.—For high-class road improvements in ordinary topography, alignment does not have much effect on cost of construction. There is no particular object in long tangents, and where an old road is being paved it is just as well to shift the center line slightly to keep on the old traveled way and take advantage of the old grading and any hard metalling that may have been placed in the past. Slight variations from the center of the right of way often save some grading expense and improve the character of the subgrade for the pavement.

In mountain-road location, alignment is given careful consideration, as it has a marked effect on cost. The radii are made as large as possible to fit the mountain side without excessive grading. On steep slopes the grade contour must be followed closely. There is no hesitation in using radii as sharp as 80′ at the head of gullies where the driver can see across the curve or a radius of 100′ on the outside curves around points where the sight distance depends on the radius. Even these limits are impracticable in very rough country where radii of 40′ are considered reasonable. All outside

curves having a sight distance of less than 250′ should be posted with danger signs.

The arbitrary limitation of minimum radius has a large effect on cost. The following example will illustrate this point. These revisions were made by C. H. Chilvers on the Rabbit Ears Pass Road in Colorado to show the effect of alignment on excavation.

The office method of plotting a good cheap alignment is described in detail in Chap. XIV (p. 1108).

RABBIT EARS ROAD, STATE OF COLORADO, SIDE-HILL SECTION

Original design	First revision	Second revision
Length, 8.79 miles Width of roadway, 16′ Maximum grade, 8 % Grades flattened on switchback turns Minimum radius, 100′ First-class alignment throughout	Length, 8.81 miles Width, 16′ Maximum grade 8 % No grade compensation on curves Minimum radius, 100′ First-class alignment but more curving, eliminating many expensive tangents	Length, 8.94 miles Width, 16′ Maximum grade, 8.5 % No compensation on curves Minimum radius, 40′ Poor, crooked alignment carried to extremes
Total amount of excavation, 91,000 cu. yd. First-class design but needlessly expensive	Amount of excavation, 65,000 cu. yd. First-class design shows effect of careful, intelligent alignment engineering	Amount of excavation, 38,000 cu. yd. Illustrates extreme effect of alignment on cost From an engineering point of view there was no justification for this design for the topography in question

NOTE.—On one switchback turn on this road a 100′ radius required 5000-cu. yd. excavation and a 40′ radius 500 cu. yd., or one-tenth as much. Short radii are justified in isolated cases but their continuous use to save small amounts is poor practice.

Effect of Railroad Grade Crossings on Alignment and Grade.—Railroad grade crossings are sources of continual danger; they should be eliminated on all main routes. Subway and overhead eliminations are discussed in Chap. IX. Specifications for approach grades and alignment are given in Chap. IX (p. 609).

Recommended Alignment Practice.—The following summary agrees with general current practice and can often be used without raising the cost beyond the bounds of reason. A summary of this nature is, of course, of only general value. Each case must be worked out on its own merits. Broad generalizations of detail requirements are dangerous if used indiscriminately.

Main commercial roads (well-settled districts):

Minimum sight distance.......................... 300–400′.

Minimum radius of curvature at right-angle turns on level outside of villages where sight distance does not control.................................... 250–400′

Minimum radius of curvature on steep grades or at the foot of such grades, depending on the central angle where the sight distance is not the controlling factor. 600–800′.

Ordinary agricultural roads (local service):

Minimum sight distance .... 200–250'.

Minimum radius of curvature at right-angle turns on level outside of villages .... 100–200'.

Minimum radius of curvature on steep grades where sight distance does not govern .... 400–600'.

Mountain roads:

No limitation on sight distance.

Warning signs used where necessary.

Minimum radius on steep grades .... 100'.

Minimum radius in extremely rough ountry, 40'. Grades not to exceed 3% for a 40' radius and 4% for an 80' radius. Any grade up to 8% on a 100' radius, although it is desirable not to exceed 5% on a 100' radius curve with a large central angle.

Minimum Driveway or Intersection Radii:

Ordinary automobiles 25' radius for turns of 90° or less
" " 35' " " " over 90°
Trucks 50' to 75' center line radii

CHAPTER III

SECTIONS, PAVEMENT WIDTHS, RIGHT OF WAY, AND CLEARING

Introduction.—The shape and the width of road cross-sections affect the safety and convenience of highway traffic and they also affect the economy of grading design. It is desirable to obtain features that are fundamentally required for the satisfaction of traffic, but it is also desirable to avoid arbitrary standardization which adds materially to the cost without any adequate benefit. The problem of sections can be summed up as the determination of the minimum widths of grading, pavement, etc., the minimum depth of surface ditches in cut and variations in shape and width that will serve traffic requirements for the life of the pavement surface (10 to 15 years). Methods of estimating future traffic volume are given in Chap. I (p. 32).

At the time a road is improved, right of way should be acquired of such a width that it will permit the future widening of section, pavement, etc. Liberal right of way can be obtained more easily during the first stages of road improvements than at a later time when the land is worth more and buildings have been erected close to the road; *that is, right of way considers the future requirements of the road but the grading and pavement widths can only reasonably consider the requirements of traffic growth expected within* 10 *to* 15 *years.*

SECTIONS

Sections will be considered from the standpoints of safety, convenience, and economy.

Safety requires a grading shape that permits vehicles to use any part of the road from ditch to ditch without overturning or, if this is not possible, various expedients, such as the one-way crown, banking on curves, guard rail or wall protection, will very materially help the traffic. Safety requires a liberal sight distance, which on sharp curves can be obtained by "daylighting" the section (see Figs. 29, p. 155 and 15, p. 115).

Convenience requires sufficient width for vehicles to pass easily at any point in ordinary topography and provides special turnouts at short intervals on mountain roads. It also calls for crown and shoulder slopes that permit driving without an uncomfortable side tilt to the rig.

Economy of grading calls for various combinations of widths, ditch depths, back slopes, etc. which most nearly fit the natural conditions at all points; that is, the section must be flexible.

It is, perhaps, best to develop the discussion of sections and pavement widths, first, for high-class roads in ordinary topography, second, for pioneer roads in mountainous conditions; and, third, for village streets.

HIGH-TYPE ROADS

Premises of Design.—The points to be considered in the development of a normal section are:

1. What is a safe driving slope?
2. What is a comfortable driving slope?
3. What pitch is required to drain different surfaces?

These factors determine the shape of the section.

4. What is the commonly used width and the maximum width of the traveled way?
5. What is the minimum allowable depth of surface ditch?
6. What are stable slopes for cut and fill outside of the limits of the traveled section?

These factors affect economy.

The first three questions have been pretty well settled by current practice; the last three are not so well defined. The following premises will, however, be assumed, which can be modified for special conditions:

1. Three inches to one foot, or 4:1 is the maximum safe driving slope.
2. One inch to one foot, or 12:1 is the maximum agreeable driving slope.
3. Pavement crown should be kept to the minimum slope required for drainage of the pavement, as the flatter the crown the better distribution of traffic over the entire pavement area and the easier it is to drive a machine except on curves, where a banked slope is desirable to counteract centrifugal force. Normal crowns on straight alignment range from 1/8 to 3/4″ per foot, depending on the pavement surface. The practical limits of banking on curves range from 1/4 to 3/4″ per foot width.
4. The width of roadway subjected to hard wear on the lighter-traffic roads (single-track less than 300 vehicles daily) ranges from 8 to 10′ and on double-track roads (300 to 6000 vehicles daily) from 14 to 20′. The maximum width of roadway subjected to some wear by traffic turning out to pass ranges from 18 to 22′ and on heavily traveled roads repair parking requires at least 7′, shoulder width on each side of the pavement proper, or a minimum out-to-out shoulder width of 32 to 34′.
5. The minimum ditch depth below crown grade depends on keeping the longitudinal surface water outside of the traveled way and is rarely less than 10″; it depends largely on the amount of surface water that must be cared for.
6. The stable cut and fill slopes depend on the climate and the soil and range from 1/4:1 to 4:1.

Items 3 to 6 will be discussed briefly and typical sections derived.

Item 3. Pavement Crown.—The following discussion applies to rural highway pavements where the shoulder is flush with the pavement surface. For curbed city or village streets, see page 173.

Normal Crown.—Satisfactory normal crowns for differe : pavements on straight alignment have the following range:

Single-track, gravel, or water-bound macadam, ½ or ⅝″ per foot of half width. Circular arc recommended.

Double-track, gravel, or water-bound macadam, ⅜ or ½″ per foot of half width. Circular arc recommended.

Double-track, bituminous macadam, or oiled water-bound macadam, 5/16 to ⅜″ per foot of half width. Circular arc recommended.

Stone block or brick with bituminous joints on concrete base, 5/16″ per foot of half width. Circular arc recommended.

Sheet asphalt, brick with cement joints, asphalt block, and wood block, ¼″ per foot of half width. Circular arc recommended.

Cement concrete, ⅛″ per foot of half width (straight-line crown), or ¼″ per foot of half width (circular arc crown).

Banked Crown on Curves.—On sharp curves it is customary to use a one-way uniform banked crown to counteract the centrifugal force. A well-banked curve reduces the tendency to skid, increases comfort, and tends to keep traffic on the right side of the road, as no advantage accrues to the driver by cutting over onto the inside of the curve to take advantage of a steeper crown slope.

The proper amount of cross-slope considers the speed of traffic and the sharpness of the curve. It must be a compromise between the requirements of traffic traveling at the maximum legal speeds and slow-moving vehicles. It must also not exceed an amount which causes horses or slow-moving trucks to sideslip when the pavement is icy or which will cause heavily loaded trucks or hay ricks to overturn on account of their high center of gravity.

Centrifugal force is expressed by the formula $\frac{MV^2}{32.2\,R}$,

in which M = weight of vehicle in lbs.
V = velocity, in feet per second.
R = radius of curve, in feet.

See speed Table 113, (p. 616), for conversion of miles per hour to feet per second.

To get the theoretically correct cross-slope in inches of rise per foot width of pavement, the following formula can be used directly.

Bank slope rise in inches per foot of pavement width $= 0.37\,\frac{V^2}{R}$

$= 0.000065\,V^2D$,

where V = velocity of vehicle, in feet per second.
R = radius of curve, in feet.
D = degree of curve.

Table 33 shows the theoretical amount of rise per foot width for different speeds and curves to counteract centrifugal force entirely.

Table 34 shows actual cases satisfactory for normal pleasure traffic in summer and also cases where slow-moving vehicles and horse traffic have trouble during the winter months.

An examination of these two tables shows that slow-moving vehicles, particularly those with high centers of gravity, limit curve

anking to ¾″ per foot of width and make it desirable to limit the ope to about ⅝″ per foot, particularly on steep hills.

From a practical standpoint it has been found desirable to bank ırves on the basis of the theoretical requirement for a 25- to 30- ı.p.h. speed up to the point where ¾″ per foot width is required, ıd for all curves sharper than this limit (600 to 900′ radius) use the .me bank, ¾″ per foot, on the assumption that high speed should : and is reduced on such curves.

Table 35 gives a good practical basis for banking curves. This ıble must be modified by judgment where reverse curves occur or :her special features, such as intersecting roads, etc. Figure 21). 128) shows three methods of gradually warping the surface from ɔrmal crown to banked crown and of gradually widening the avement on a curve to get a good practical transition curve. here is no object in road work in figuring a theoretical center-line ansition curve similar to railroad practice.

ABLE 33.—THEORETICAL BANKING ON CURVES IN INCHES PER FOOT WIDTH OF PAVEMENT

$$0.37\frac{V^2}{R} = 0.000065\,V^2D$$

V = velocity in ft. per second.
R = radius of curve in feet.
D = degree of curve.

Radius of curvature, in feet	Banking for different speeds, inches per foot width			
	10 m.p.h.	20 m.p.h.	30 m.p.h.	40 m.p.h.
5730 = 1° curve	...	1/16	⅛	7/32
5000	...	...	5/32	9/32
4000	...	3/32	3/16	11/32
3000	...	⅛	¼	7/16
2000	...	3/16	⅜	⅝
1500	1/16	¼	½	14/16
1000	...	⅜	¾	1 5/16
800	...	7/16	⅞	1⅝
600	⅛	⅝	1¼	2⅛
573 = 10° curve	⅛	⅝	1¼	2¼
400	5/32	⅞	1 13/16	3⅜
300	¼	1	2⅜	4¼
200	⅜	1¾	3⅝	6⅜
100	¾	3½	7¼	12¾

NOTE.—For conversion of speed, miles per hour to feet per second, see able 113 (p. 616).

TABLE 34.—EXAMPLES OF SATISFACTORY AND UNSATISFACTORY CURVE BANKING IN USE

Radius of curvature, in feet	Grade of road, per cent	Total bank	Bank slope, in inches per foot, width of pavement
Satisfactory banks for high-speed traffic with dry pavement surface			
1146 = 5°	Level	10″ in 16′	5/8
818 = 7°	Level	11″ in 21′	1/2
764 = 7° 30′	Level	11″ in 16′	3/4
674 = 8° 30′	Level	12″ in 19′	5/8
573 = 10°	0.8	15″ in 20′	3/4
286 = 20°	2.0	12″ in 16′	3/4
573 = 10°	5.0	9″ in 16′	5/8
498 = 11° 30′	6.2	12″ in 20′	5/8
Unsatisfactory banks for slow-speed trucks and horse traffic when pavement is slippery with light rain or sleet (sideslip occurs)			
573 ≐ 10°	3.2	15″ in 20′	3/4
716 = 8°	7.0	12″ in 18′	2/3

TABLE 35.—PRACTICAL BASIS FOR BANKING CURVES, CONSIDERING BOTH HIGH-SPEED MOTOR TRAFFIC AND SLOW-SPEED TRAFFIC BOTH MOTOR AND HORSE DRAWN

Radius of curvature, in feet	Cross-slope rise, in inches per foot of pavement width	
	On grades less than 5%	On grades of 5% or steeper
2000	1/4 (Theoretical bank 25 m.p.h.)	3/16
1500	3/8 (Theoretical bank 25 m.p.h.)	1/4
1000	1/2 (Theoretical bank 25 m.p.h.)	3/8
800	5/8 (Theoretical bank 25 m.p.h.)	1/2
600	3/4 (Theoretical bank 25 m.p.h.)	5/8
400	3/4	5/8
300	3/4	5/8
200	3/4	5/8
100	3/4	5/8

NOTE.—The rates recommended must be modified by judgment where reverse curves or intersecting roads occur. Curves with a radius of more than 2000′ are rarely banked on main tourist roads. On local service roads carrying less than 1500 vehicles daily curves over 1000′ radius are rarely banked.

Variable Bank to Accommodate Both High- and Low-speed Traffic.—There is more and more demand for relatively high banking to accommodate high-speed motor traffic, and some designers hold to

the 30-mile theoretical bank taking care of the slow-moving traffic by level stone-surfaced shoulders for double-track pavements and using a reverse parabolic cross-bank on pavements wide enough for four lanes of traffic, as shown in Figs. 19 and 20.

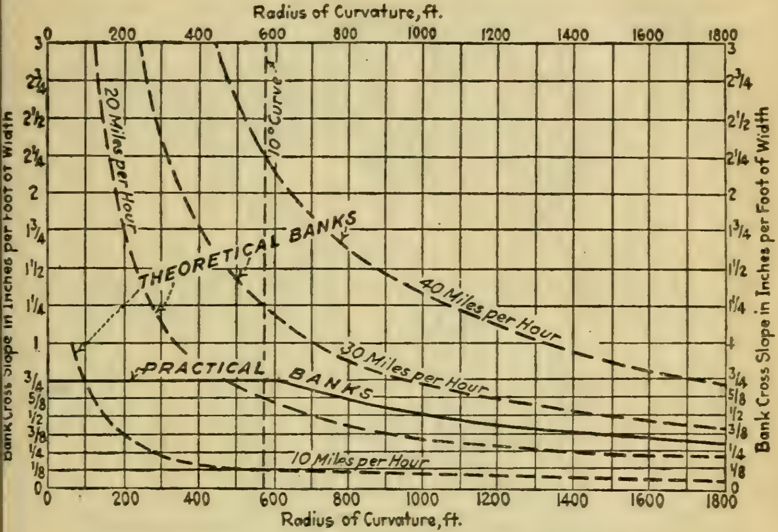


FIG. 18.—Graph of theoretical and practical bank slopes on curves.

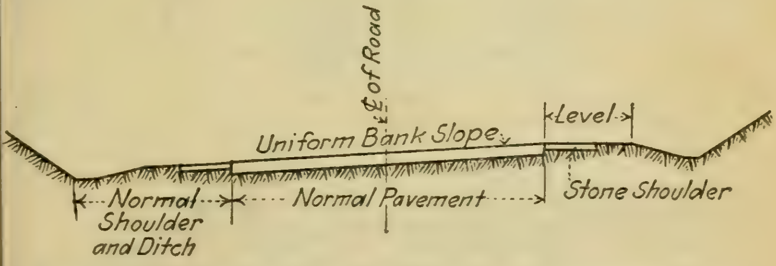


FIG. 19.—Typical grading section uniform pavement bank.

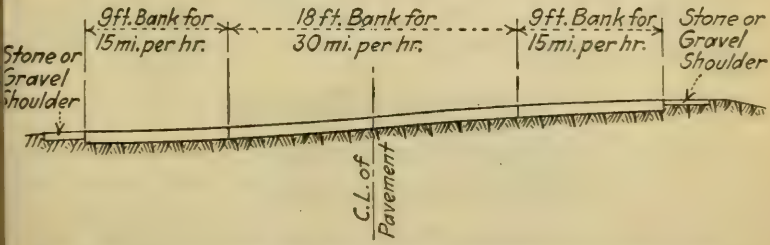


FIG. 20.—Variable bank pavement section 4 lines of traffic.

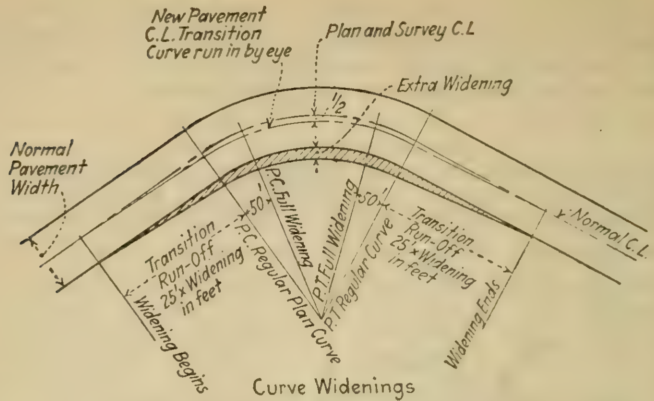


FIG. 21*A*.—Change from normal to banked crown at curves (Plan)

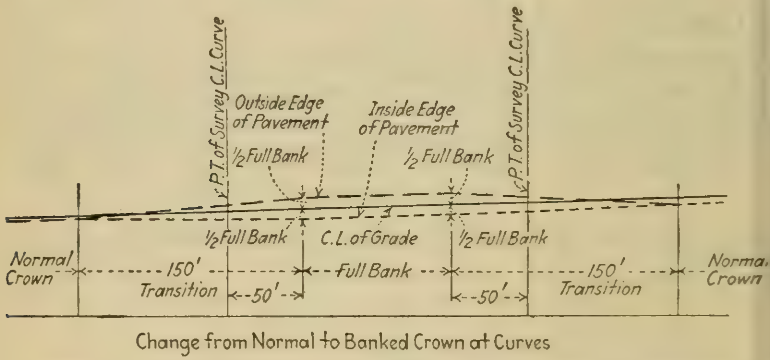
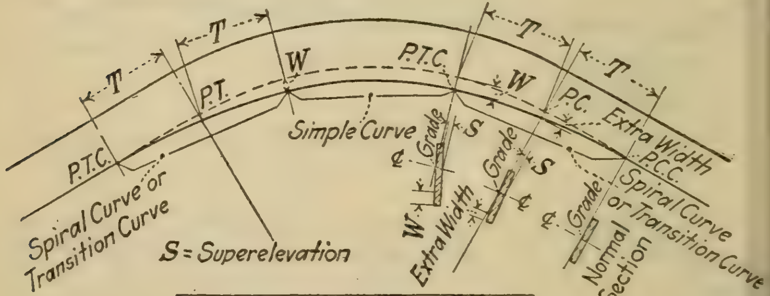


FIG. 21*A*.—Changing crown at banked curves (Profile).

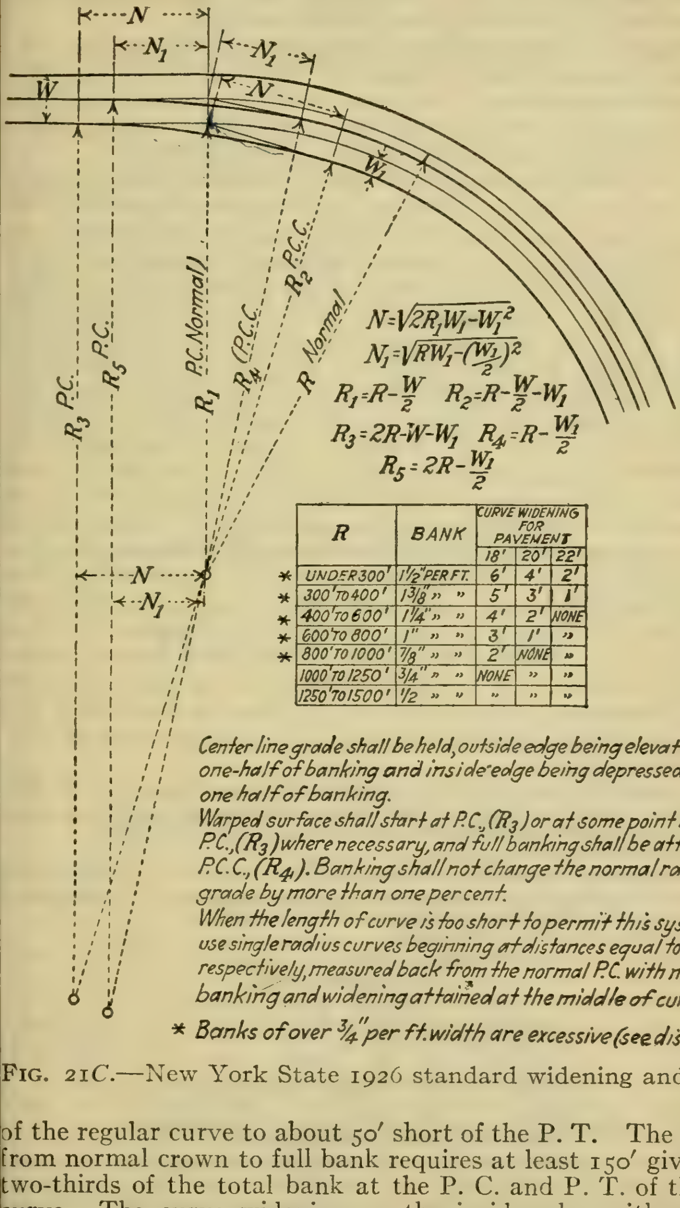


SUPERELEVATION AND WIDENING			
CURVE RAD.	SUPERELEVATION	EXTRA WIDTH "W"	DISTANCE "T"
UP TO 300'	1" PER FOOT	3'-6'	75'-100'
300'-500'	3/4" " "	1'-3'	50'-75'
500'-1000'	1/2" " "	0'	50'
CENTER LINE TO BE HELD AT THEORETICAL GRADE			

FIG. 21*B*.—U. S. Bureau of Public Roads 1925 standard widenin[g] and banking.

Changing Crown.—Figure 21 shows three typical methods of changing from normal to banked crown on curves.

The full bank coincides with the location of the full widening of the curve and extends from about 50′ beyond the theoretical P. C.



$$N = \sqrt{2R_1W_1 - W_1^2}$$

$$N_1 = \sqrt{RW_1 - \left(\frac{W_1}{2}\right)^2}$$

$$R_1 = R - \frac{W}{2} \quad R_2 = R - \frac{W}{2} - W_1$$

$$R_3 = 2R - W - W_1 \quad R_4 = R - \frac{W_1}{2}$$

$$R_5 = 2R - \frac{W_1}{2}$$

	R	BANK	CURVE WIDENING FOR PAVEMENT		
			18′	20′	22′
*	UNDER 300′	1½″ PER FT.	6′	4′	2′
*	300′ TO 400′	1⅜″ " "	5′	3′	1′
*	400′ TO 600′	1¼″ " "	4′	2′	NONE
*	600′ TO 800′	1″ " "	3′	1′	"
*	800′ TO 1000′	⅞″ " "	2′	NONE	"
	1000′ TO 1250′	¾″ " "	NONE	"	"
	1250′ TO 1500′	½ " "	"	"	"

Center line grade shall be held, outside edge being elevated one-half of banking and inside edge being depressed one half of banking.

Warped surface shall start at P.C., (R_3) or at some point back of P.C., (R_3) where necessary, and full banking shall be attained at P.C.C., (R_4). Banking shall not change the normal rate of grade by more than one per cent.

When the length of curve is too short to permit this system to work, use single radius curves beginning at distances equal to N and N_1 respectively, measured back from the normal P.C. with maximum banking and widening attained at the middle of curve

* *Banks of over ¾″ per ft. width are excessive (see discussion)*

FIG. 21*C*.—New York State 1926 standard widening and banking.

of the regular curve to about 50′ short of the P. T. The transition from normal crown to full bank requires at least 150′ giving about two-thirds of the total bank at the P. C. and P. T. of the regular curve. The curve widening on the inside edge with center line shifted one-half of widening at all points gives a good practical transition curve.

The normal grade is carried around the center line of the pavement curve, the inside edge dropped, and the outside edge gradually raised as shown in Fig. 21. It is sometimes desirable to hold the inside at normal grade and bank entirely by raising the outside. Each case depends on local conditions and center-line grade profile, and the method should be left to the field engineer.

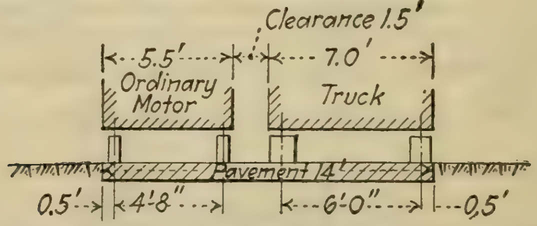
Current practice favors the bank slopes given in Table 35 (p. 126).

Item 4. Pavement and Shoulder Widths.—Pavement and shoulder widths are affected by volume of traffic, width of vehicles commonly using the road in question, type of pavement, sharp curvature, and the cost of construction and maintenance.

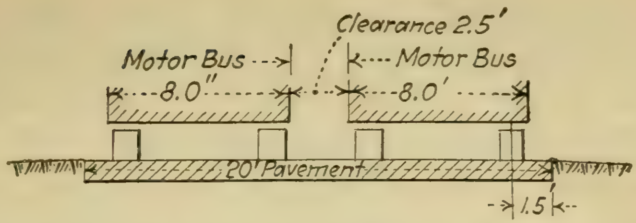
Volume of traffic classes the road roughly as single track, double track, or multiple track. Width of vehicles, safe clearances, and curvature control the width of traffic lanes on double-track or multiple-track roads. The ordinary passenger automobile has a body width about 5′ 6″ and a wheel gage of about 4′ 9″. Large trucks have a body width of about 7′ to 7′ 6″ and a wheel gage of about 5½ to 6′. Motor busses have a body width of about 8′. Traffic regulations generally limit the body width of vehicles to 96″ except traction engines, which may be 110″. Safe clearances are entirely a matter of volume of traffic and speed. For light-traffic roads where it is only necessary to turn out occasionally to pass and where such occasional passing justifies reduction in speed and careful driving it is proper to compute the pavement width on the basis of the outer wheel being placed within 6″ of the edge of the pavement or armored shoulder and allowing a clearance between vehicles of 1.5′ on straight alignment and 2 to 3′ on curves. For heavily traveled roads with continuous double-line or multiple-line traffic traveling at speeds of 25 to 40 m.p.h. the clearance between vehicles should not be less than 2½′ for ordinary cars or motor busses nor less than 2′ for trucks increased to 3′ on curves and the location of the outer wheel should not be closer to the edge of the pavement or armored shoulder than 2′ for ordinary autos or 1½′ for trucks.

Motor busses traveling at high rates of speed seem to be the controlling type of vehicle in establishing widths of traffic lanes on main highways (1926).

The following diagrams illustrate the width of pavements required on double-track roads for the two extremes of clearance outlined in the preceding paragraph.



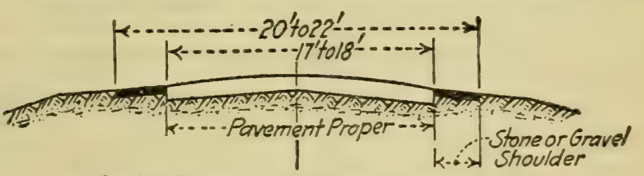
Light-traffic Roads.—On these roads it does no harm if light vehicles turn off the pavement to pass, provided stone, gravel, or firm earth shoulders are provided for such turn-out traffic.



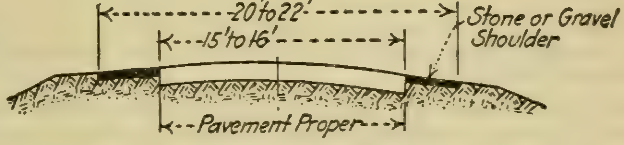
Main intercity roads, motor-bus requirements (straight alignment).

NOTE.—Diagrams on page 135 show distribution of traffic on pavements of different widths.

These conditions have resulted in the following common practice, which is summarized in Table 36 for straight alignment. Table 37 shows widths required on curves to allow for extra clearance and rear-wheel encroachment discussed on page 116. Single-track pavements (less than 300 vehicles daily) range in width from 8 to 12′, depending on the type of pavement, 8′ to 10′ being used for the harder surfaces and 10′ to 12′ for gravel or sand clay. Double-track roads (300 to 6000 vehicles daily) range in pavement width



Rigid Pavements, Class II Roads



Macadam Pavements, Class II Roads

FIG. 22.—Comparative pavement and armored shoulder widths Class II traffic.

from 15 to 20′ on straight alignment with special stone shoulders (see Fig. 22).

For rigid-type pavements on double-track roads a width of less than 18′ is inadvisable on account of the formation of dangerous ruts along the pavement edge, the added cost of shoulder maintenance (see p. 525), and the undesirability of heavily loaded wheels traveling close to the outside edge, which increases the probability of corner crack failure (see design of rigid pavements, p. 368). For macadam pavements with stone shoulders it is permissible to cut below this width for traffic of less than 1500 vehicles daily.

For multiple-line traffic an allowance of 9′ per traffic lane is common practice for straight alignment widened on curves for rear-wheel encroachment (see p. 116). Ten feet per traffic lane is advocated by some engineers where there is much motor-bus traffic.

TABLE 36.—COMPARATIVE WIDTHS
(In feet)

Class of road	Vehicles per day	Rigid pavements		Macadam or gravel	
		Pavement proper	Out-to-out width armored shoulders	Pavement proper	Out-to-out width armored shoulders
Class I[a]	2000–6000	18–20	22–24	18–20	22–24
Class II	800–2000	17–18	20–22	15–16	20–22
Class III	300– 800	16	16	12–16	16
Class IV	Less than 300	......	......	8–12	

[a] For traffic of over 6000 daily (10-hr. count in summer) increase pavement width to 27 or 36′. See page 28 for discussion of road capacity.

TABLE 37*A*.—CLASS I TRAFFIC (SHARP CURVES)

Radius of road center line, in feet	Total pavement width, in feet	Length tangent run-off, in feet Fig. 21*A*, p. 128
100	25	100
150	24	90
200	23	90
300	22	80
400	22	80
500	21	70
600	21	70
800–1000	20	60

NOTE.—Normal pavement widths of 18 to 20′ used on all curves having a radius greater than 1000′.

TABLE 37*B*.—CLASS II AND III TRAFFIC (SHARP CURVES)

Radius of road center line, in feet	Total pavement width on curves for a double-track road (local service), in feet	Length tangent run-off, in feet Fig. 21*A*, p. 128
50	29	100
75	25	100
100	23	100
150	22	90
200	21	90
300	20	80
400	20	80
500	19	70
600–800	18	50

NOTE.—Normal pavement width (15 to 18′) used on all curves having a radius greater than 800′.

Changes in Pavement Width.—Special extra width is used on rves, at railroad crossings, at long span bridges, and through vil-;es. In changing from narrow to wider widths the following ιes have been found to give satisfactory results.

For curves widened on one side only where the center line of the vement shifts one-half the total widening the length of transition ›m normal pavement width to extra-wide width should be at .st 20 to 30′ for each foot of flare for the edge of the pavement ·e Fig. 21, p. 128).

For widenings on straight alignment or curves approaching rail-ıd crossings, bridges, etc. where the vehicle must swerve first to ꞓ right and then straighten out again, a distance of 30 to 40′, per ›t flare of edge of pavement is required (see Fig. 193, p. 607).

Effect of Pavement Width on Cost.—Table 38 shows approximate nstruction cost per foot width of pavement per mile. It can be ıdily seen that where funds are limited it is desirable to select a ısonable minimum which will meet traffic requirements.

TABLE 38.—PAVEMENT COSTS

Type of pavement	Assumed cost per square yard	Cost per foot width 1 mile long
rick	$4.50	$2700
sphalt concrete	3.50	2100
ement concrete	3.20	1920
enetration bituminous macadam	2.20	1320
Vater-bound macadam	1.80	1080

It is well to bear in mind that the pavement can always be widened by : maintenance or by reconstruction at a later period when the traffic 'ume increases sufficiently to warrant added width and that it is ·ely advisable to select the width for a volume of traffic greater than pected in 15 years, as this is about the usual life of rural highway vement surfaces.

Shoulder Width.—Shoulder width to permit turnout traffic pends on the same factors as pavement width with the added ovision for standing rigs outside of the pavement area on heavily ıveled roads.

Table 39 shows the results of Massachusetts investigations 1896 1900. These results were obtained under the old horse-drawn ıffic conditions and do not apply closely for the conditions of day. They are included in connection with this discussion to ıstrate the change which modern automobile traffic has made in dth requirements on the heavier-traffic roads. They, however, ow a general relation between areas of light and heavy traffic on e lighter-traveled agricultural roads.

The second part of Table 39 gives the results on a few roads, owing the form used and the variations from year to year. The ›tnote gives a summary of 160 roads and shows the results ıch better than by printing the table in full.

Stated briefly, the widths subjected to continuous wear (unimportant roads ranged from 8 to 10′, on well-traveled roa 10 to 14′, and in unusual cases, 14′ to 16′. The maximum widt for turnout traffic varied from 12 to 14′ on side roads and 17 to 1 on the main roads.

Modern traffic has changed conditions on the main roads, b does not greatly affect these figures on the lighter-travel roads 1 to about 300 vehicles per day. Similar widths on New York Sta main roads have been measured and found to check the widt of heavy travel of 14 to 16′ but the maximum turnout widths we more, running from 20 to 22′. This can be explained by the increa in automobile traffic which, on account of its higher speed, requir more room in passing.

TABLE 39.—SHOWING WIDTHS OF TRAVELED WAY

Town or City	County	Width of Macadam	Maximum Width of Traveled Way				Width of Commonl Traveled Way			
			1896	1897	1898	1899	1896	1897	1898	189
Athol	Worcester .	17′	16′	16′	20′	18′	10′–12′	12′	14′	14′
Barre	Worcester .	15′	—	13′	14′	14′	—	9′	7′	8′
Bedford	Middlesex .	15′	—	12′	15′	15′	—	8′	10′	9′
Chicopee	Hampden .	20′	—	20′	20′	20′	—	12′	12′	13′
Dalton	Berkshire .	15′	20′	20′	21′	16′–21′	20′	16′	18′	12′–1
Fitchburg (W.)	Worcester .	15′	15′	14′	18′	18′	10′	10′	15′	14′
Huntington ..	Hampshire.	15′	9′	11′	11′	12′	7′	8′	9′	8′
Lincoln	Middlesex .	15′	15′	15′	15′	15′	10′	9′	10′	10′
Marshfield ...	Plymouth..	15′	14′	12′	11′	12′	8′	9′	7′	7′
North Adams	Berkshire .	15′	10′–12′	13′	14′	15′–20′	8′–10′	9′	10′	12′
Orange	Franklin ..	17′	16′	16′	20′	20′	10′–12′	12′	15′	15′
Taunton	Bristol	15′	20′	20′	15′	18′	10′–15′	10′	8′	7′–1

Width of traveled way on 160 roads in Massachusetts, measured durin the years 1896, 1897, 1898, and 1899, and printed in the report of th Massachusetts Highway Commission for 1900.

The width of stone on these roads is given as 15′ wide on 130, 12′ wid on 3, and 10′ wide on 2. It should be remembered that the stone is pu on very much thicker in the middle than at the edges.

The maximum width of traveled way as measured was as follows:

9 ft. wide on	2 roads	18 ft. wide on	23 roads
10 " " "	6 "	19 " " "	1 "
11 " " "	2 "	20 " " "	10 "
12 " " "	28 "	21 " " "	10 "
13 " " "	8 "	22 " " "	1 "
14 " " "	23 "	24 " " "	2 "
15 " " "	30 "	25 " " "	4 "
16 " " "	8 "	26 " " "	1 "
17 " " "	1 "	33 " " "	1 "

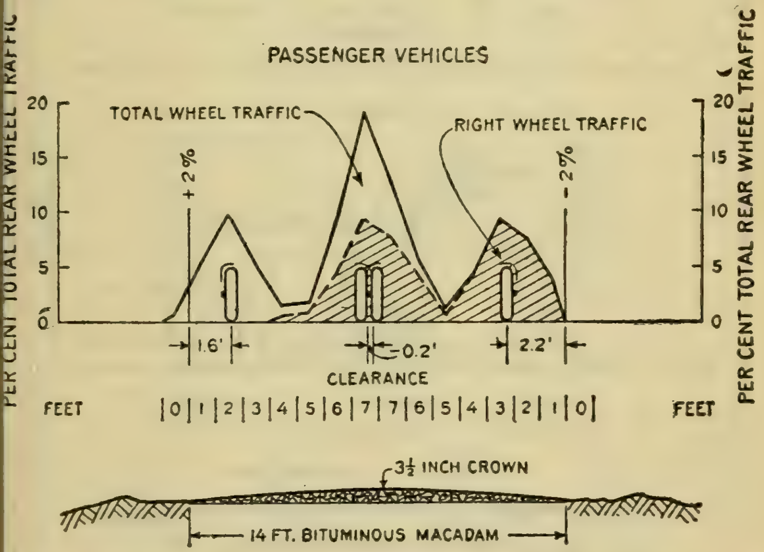
The width of commonly traveled way as measured was as follows:

7 ft. wide on	12 roads	14 ft. wide on	8 roads
8 " " "	17 "	15 " " "	13 "
9 " " "	25 "	16 " " "	2 "
10 " " "	32 "	18 " " "	4 "
11 " " "	10 "	20 " " "	2 "
12 " " "	30 "	22 " " "	1 "
13 " " "	3 "	25 " " "	1 "

Even a single-track pavement should have ample shoulder width permit traffic to turn out and pass easily; that is, the total width pavement and driving shoulder, no part of which should have a ppe of more than 1″ to 1′, is practically the same for single- or uble-track roads.

For roads having a volume of traffic of over 1500 vehicles daily a iving shoulder width of at least 7′ is required to permit parking, a great many accidents have occurred due to vehicles standing the pavement area of double-track roads.

The following diagrams illustrate typical transverse distribution traffic on different width pavements. These diagrams are taken om an article by J. T. Pauls of the U. S. Bureau of Public Roads iblished in *Public Roads*, March 1925, and verify the foregoing xt. This investigation of the U. S. Bureau is the most complete udy that has been made in transverse distribution of traffic under odern traffic conditions.



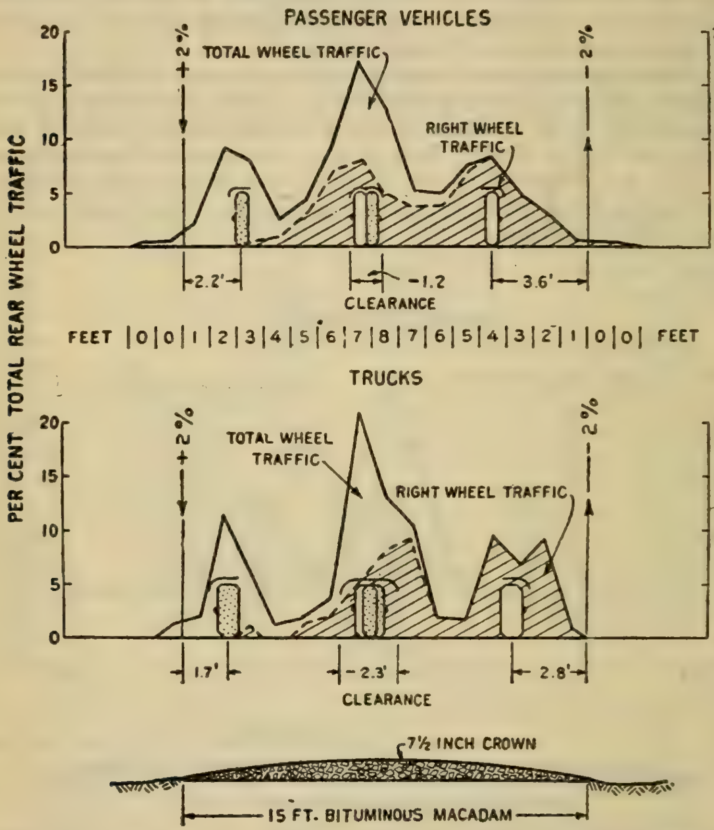
Test 9 shows the distribution of traffic on a 14′ bituminous acadam road. Note that the traffic spreads out into the shoulder the left. This fact and the lower crown make the negative earance on this road less than that of the 15′ road shown in Fig. 4.

Recommended Practice, Pavement and Shoulder Widths.—The ailable data obtained from observations on actual traffic movement indicate that a minimum turnout width of 20′ is desirable on ngle-track side roads, 22′ on secondary double-track roads, and to 32′ on main double-track special-service roads; for a triple ne of traffic 41′, and a four-track road 50′.

From these data it appears that modern practice on single- and uble-track roads requires a width of solid pavement of from 10 20′ on straight alignment and a total driving width, including

shoulders, of from 20 to 32′. These widths are modified for sha alignment, as previously discussed.

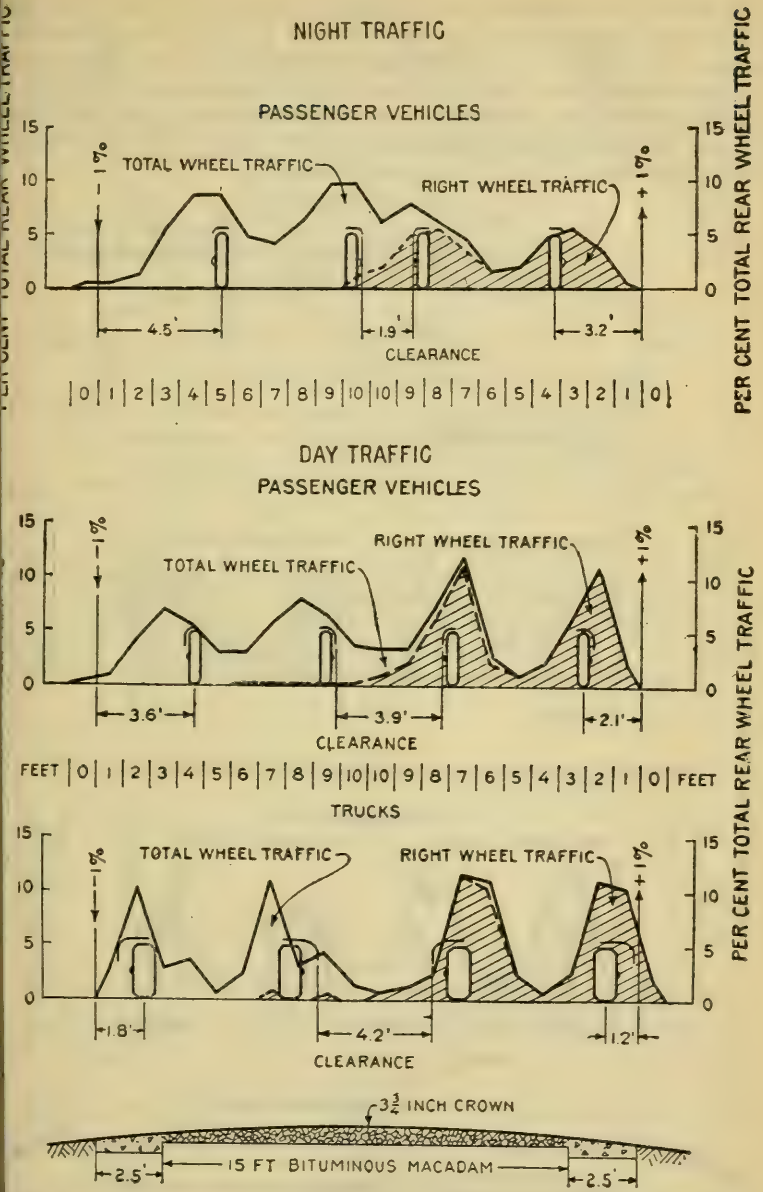
A standard for the portion of the section used for driving (F 23) has now been practically developed. The pavement that is carry the heavy traffic has a specified crown for each variety a ranges from ⅛ to ¾″ to 1′. The shoulder slope from the edge



Test 7, made on a 15′ road, shows how the maximum concentı tion of traffic occurs at the center on roads of such narrow widt The steep crown in this case accentuates the concentration at t center; and the effect of a slight downhill grade is noticeable in t greater distance of the average wheel position from the edge the downhill side.

the pavement to the limits of the driving width (20 to 32′) has slope of 1″ to 1′ or possibly ¾″ to 1′; that is, the shape of the dri ing portion of the normal section is fixed. The flexibility of t section depends on the portion outside of this driving width.

The function of the extra width is to keep the longitudinal drai age of surface water beyond the portion used for driving. To



'est 5 shows the separating effect of concrete shoulders on tan-
ts and difference in the distribution of traffic at night. Com-
e with the concrete road of the same width shown in Fig. 23
ch has a center line for the separation of the traffic.

this, there is a limitation of a minimum slope of 1″ to 1′ to insı transverse drainage and a maximum of 3″ to 1′ on the score safety. It is by the good judgment of the designer in using varic slopes between these limits and various widths and depths of ditcl combined with the possibilities of different grades, that the ecoı mies in earthwork are effected and at the same time the design made appropriate to the local conditions.

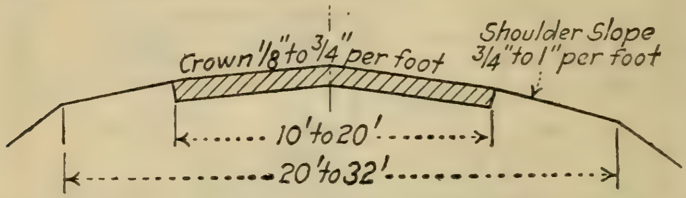
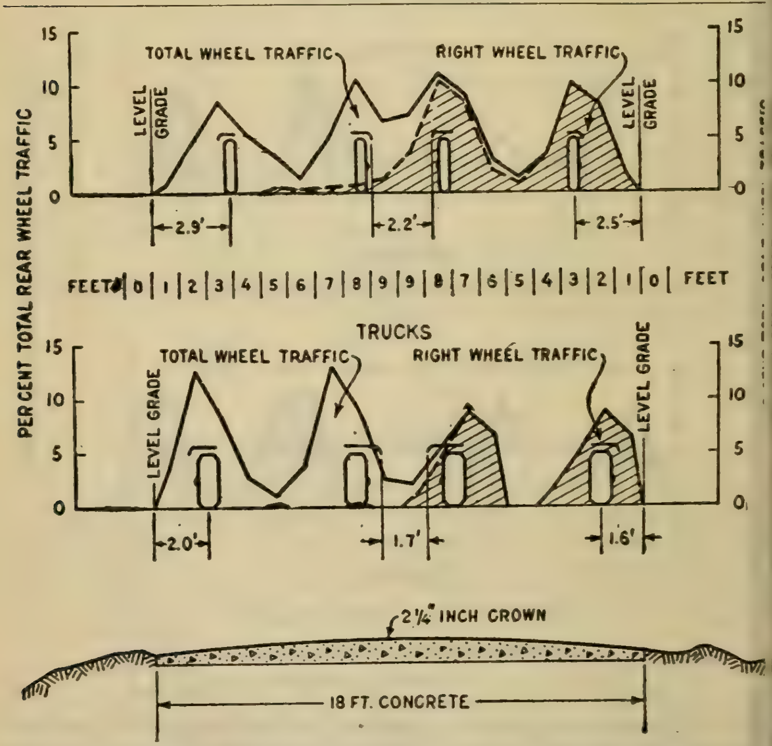
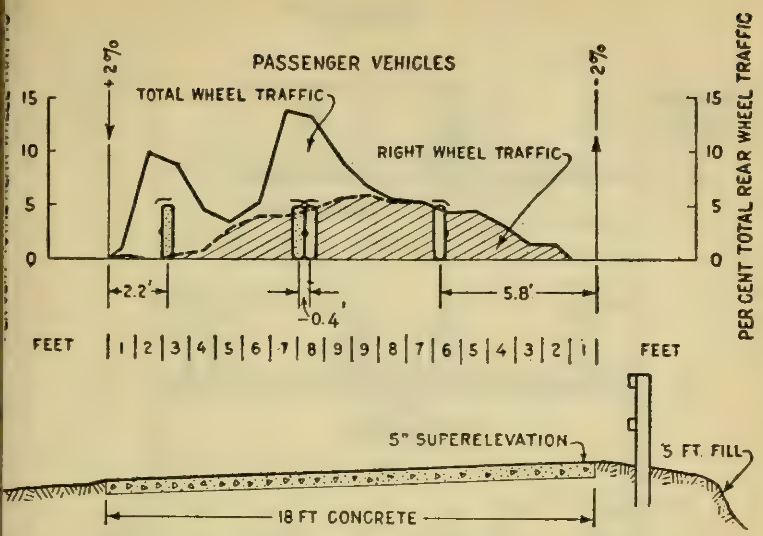


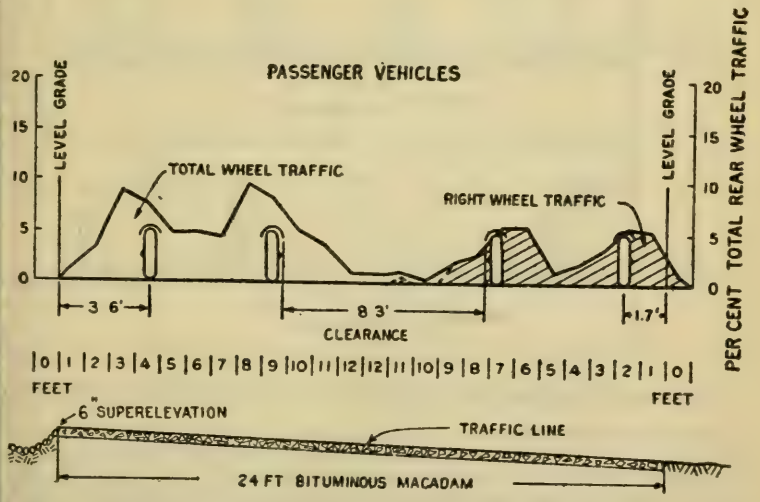
FIG. 23.—Normal pavement and shoulder section. (Traffic l than 5000 daily 10 hour count in summer.)



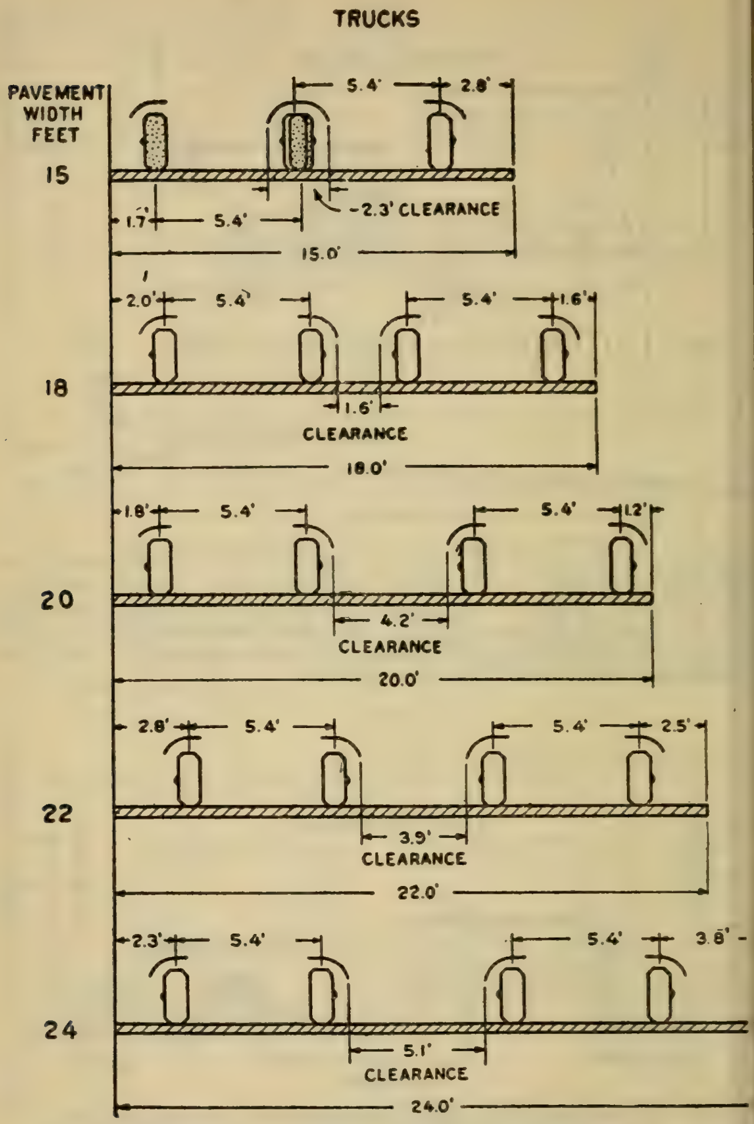
Test 4, on an 18′ concrete pavement, shows how the center tra concentration which characterizes the narrow roads is relieved widening. The good shoulders on this road encourage traffic to the surface to the very edge. Contrast this condition with tl shown in Figs. 15 and 16, where a bad shoulder condition clea discourages the use of the edges of the surface.



Test 22, made on an 18′ concrete pavement at a 25° curve with ıne superelevated section and no center line, shows the effect the absence of the center line and the presence of a menacing at the outside of the curve on the distribution of traffic. The ft toward the inside of the curve is accentuated by the slight wnhill grade at the outside.

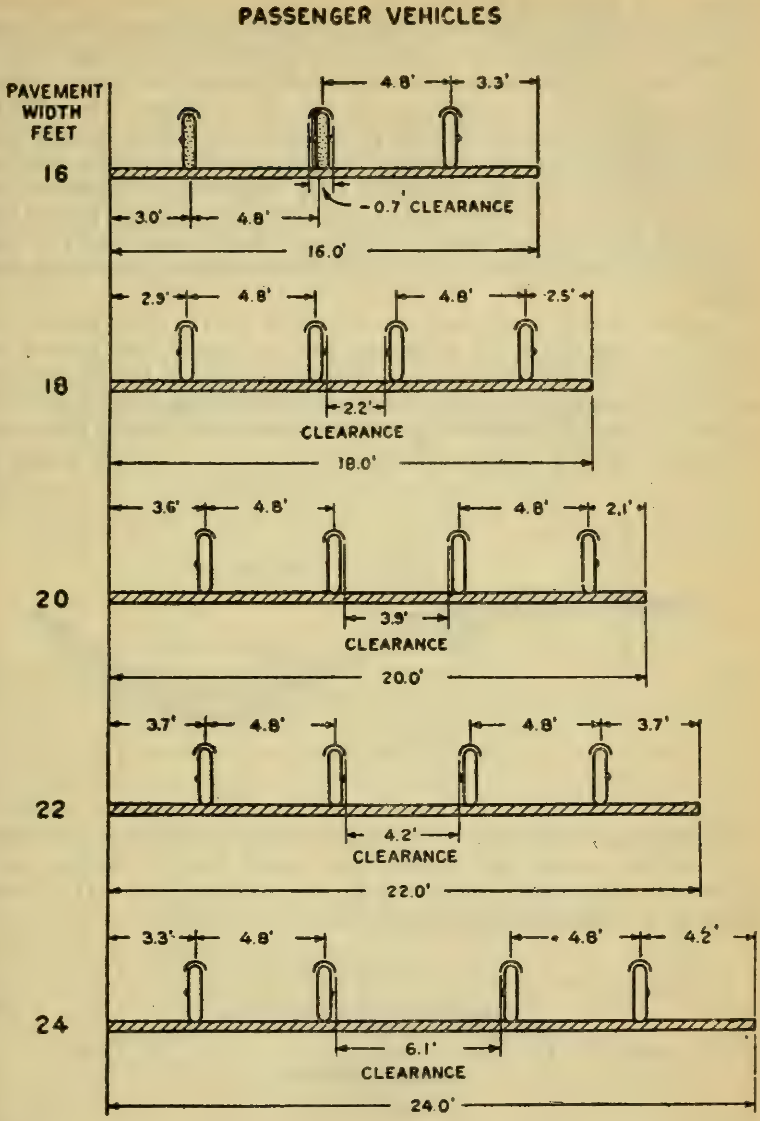


Γest 19, made on a 24′ bituminous macadam road at a 20° curve h a plane superelevated section and center line, shows a better aration of the traffic than Test 16 (Fig. 9) made on a similar road h crowned superelevated section.



Clearance diagram for truck. Preferential driving locatio

Average distribution of traffic on road surfaces of various wid from 15 to 24′. Eighteen feet is the minimum width which gi positive clearance for all vehicles in passing at the preferred p tion. The clearance increases with the width of the pavement, becomes unnecessarily large when the width exceeds 20′. Wid of 22 and 24′ are apparently excessive for two lines of traffic, not great enough for three lines.



Clearance diagram for passenger autos for preferential driving position.

Average distribution of traffic on road surfaces of various widths from 15 to 24′. Eighteen feet is the minimum width which gives positive clearance for all vehicles in passing at the preferred position. The clearance increases with the width of the pavement, but becomes unnecessarily large when the width exceeds 20′. Widths of 22 and 24′ are apparently excessive for two lines of traffic, and not great enough for three lines.

Item 5. Depth of Ditches.—The authors' experience indicates that an open ditch does not have much effect on ground water; that its part in the design is to drain the surface water, and that if ground water is encountered underdrains must be used. These conclusions have been borne out in practice and are advocated by many engineers, notably Irving W. Patterson of Rhode Island, who has had unusual success with his drainage and foundation designs. The principle to be emphasized is that deep surface ditches below the elevation of the bottom of the pavement foundations are useless. Deep ditches are not only useless but dangerous, and the best practice calls for the least depth of ditch that will handle the surface water.

A great many road men seem to feel that a deep open ditch really helps to drain the subgrade but, as stated, the author has never been able to prove by cases where foundation failure occurred that the depth of surface ditch had any well-defined bearing on the matter, provided the ditch carried away the surface water promptly. Some soils have a strong capillary action and the water works up

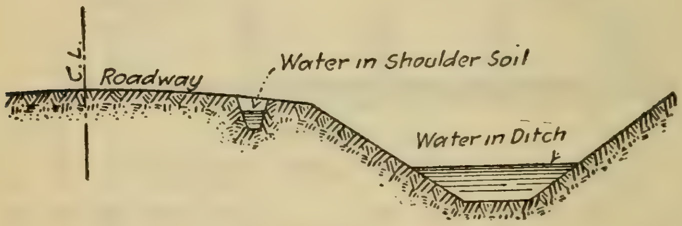


FIG. 24.

through them. In impervious soils, such as clay, a surface ditch 15′ from the center line cannot have much drawing action, as in numerous cases small holes dug in the roadbed (Fig. 24) fill with water at a much higher elevation than the side ditch.

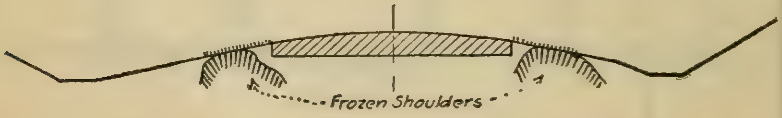


FIG. 25.

In many instances in the northern states the ground under the pavement proper thaws out before the shoulder material, which is protected by a sod coating, and the following result is obtained (Fig. 25). Under these conditions the moisture in the center is held even in porous soils. As a matter of fact, all pavement foundation design must be predicated on the assumption that, even with the best

drainage schemes, the subgrade will at times soften somewhat, and for this reason the use of deep ditches which are inconvenient to traffic and which increase the grading cost are not in so much favor as in the past.

Frequent culverts are desirable to rid the ditches of excess water. It should be remembered that road ditches are to protect the road and not furnish farm drainage and that deep farm ditches should be kept away from the road section.

The following Rhode Island standard grading sections (Fig. 26) show the use of the shallow 12″ ditch which is advocated wherever a small amount of surface water is expected.

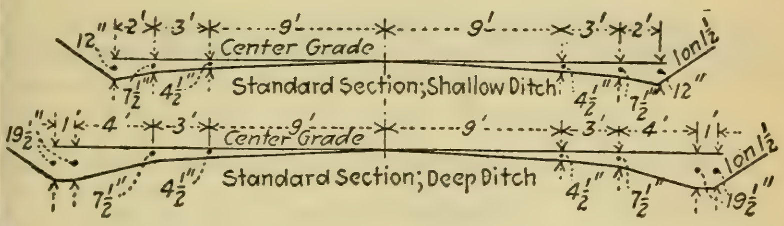


FIG. 26.—Rhode Island standard grading sections.

The following section (Fig. 27) represents a good typical minimum width and a minimum ditch depth grading section for single- or double-track roads which have been proved by practice to be satisfactory where small amounts of surface water are encountered. This section results in about the least feasible amount of cut and fill in grading design for light cuts and fills. The approximate carrying capacity of ordinary road ditches and the limitations of use of the

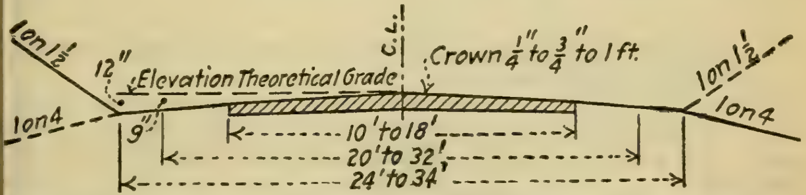


FIG. 27.—Typical minimum depth ditch section. (Traffic less than 5000 daily.)

shallow and medium road ditches are discussed under Longitudinal Drainage (p. 334).

Effect of Grading Width on Cost.—The width of grading from ditch to ditch has a distinct effect on cost, but no general relation can be established for the ordinary road improvement where an old road forms the basis for the new grading. Two examples are given to show the value of reasonable reduction in sectional widths.

1. Indian Falls.—Corfu Road in New York State

Length 1.85 miles

No change in profile.
No change in ratio of cut to fill.

Original Design	Revised Design
Width of macadam, 14′.	Width of macadam, 14′.
Width of section, 30′.	Width of section, 24′.
Depth of ditch, 18″.	Depth of ditch, 14″.
Original estimated excavation, 7500 cu. yd.	Revised estimated excavation 5200 cu. yd.

This change in section alone resulted in a saving of 2300 cu. yd. excavation, or at a rate of 1240 cu. yd. per mile, or, in money, about $1200 per mile with excavation at $1 per cubic yard.

2. Pittsford.—North Henrietta Road in New York State

Length 2.67 miles

Original Design	Revised Design
Width of section, 30′.	Width of section, 24′.
Depth of ditch, 18″.	Depth of ditch, 12 to 14″.
Ratio of cut to fill, 1.35%.	Ratio of cut to fill, 1.25%.
Maximum grade, 5.0%.	Maximum grade, 5.0%.
Profile, designed with straight instead of rolling grades and tangents of 100′ between vertical curves.	Profile, rolling grade and reverse vertical curves used.
Original estimated excavation, 11,450 cu. yd.	Revised estimated excavation 6620 cu. yd.

A saving of 4820 cu. yd., 1800 cu. yd. per mile, or, in money, approximately $1800 per mile.

The revised design on this road is a good example of what can be saved by the use of a section that fits the conditions, a rolling grade, and a ratio of cut to fill that experience has shown to be sufficient.

Item 6. Stable Cut and Fill Slopes.—Economy of design and maintenance are affected by the selection of reasonably stable slopes. For the class of grading usually encountered on roads built in ordinary topography their effect on construction cost is not great and they do not generally receive much attention, but for mountain roads, cut and fill slopes are an important consideration in the design and their effects on cost are worth considering.

Table 128 (p. 786), shows the effect in detail of various cut and fill slopes on yardage of the ordinary side-hill mountain-road sections. To illustrate the point one typical case for, say, an ordinary double-track section (S-14), Table 128, will be quoted.

Natural ground surface cross-slope, in degrees	Approximate yardage per mile		
	Cut slope 1½ : 1, fill 1½ : 1, in cubic yards	Cut 1¼ : 1, fill 1½ : 1, in cubic yards	Cut 1 : 1, fill 1½ : 1, in cubic yards
5	1,100	950	900
10	2,200	2,000	1,900
15	4,000	3,600	3,300
20	7,900	7,000	6,100
25	.....	11,700	10,200
30	.....	......	19,600

Occasional slides cannot be avoided, but continual slipping shows or design and makes both the maintenance costly and travel ngerous.

Stable slopes vary for different materials and for the same mateal under different climatic conditions. A combination of moisture d frost requires the flattest slopes for ordinary soils. On account the great variety of circumstances affecting the design, no hardd-fast rules can be laid down, but the following table, based on ilroad and highway practice, indicates the slopes that are generly used. In this table and throughout the text slopes are referred as 1½ : 1, etc., meaning 1½ horizontal to 1 vertical. In some the state standard illustrations, however, slopes are shown as on 1½, meaning 1 vertical on 1½ horizontal. It is unfortunate at an engineering requirement is expressed by two different ethods in such a conflicting order, and care must be taken to derstand which expression is used.

TABLE 40.—STABLE CUT AND FILL SLOPES

Material	Climatic conditions					
	Combined rain and heavy frost		Rain but not much frost		Arid regions, not much frost	
	Cut	Fill	Cut	Fill	Cut	Fill
and	1½ : 1 2 : 1	1½ : 1 2 : 1	1½ : 1 2 : 1	1½ : 1 2 : 1	2 : 1 4 : 1	2 : 1 4 : 1
ravel	..... 1½ : 1	..... 1½ : 1	1½ : 1 1 : 1	..... 1½ : 1	1½ : 1 1 : 1	1½ : 1
oam	1½ : 1	1½ : 1	1½ : 1	1½ : 1	1¼ : 1	1½ : 1
lay	1½ : 1 2 : 1	1½ : 1 4 : 1	..... 1 : 1	1½ : 1 3 : 1	1 : 1 ¾ : 1	1½ : 1
oulders and earth	1½ : 1	1½ : 1	1 : 1	1½ : 1	1 : 1	1½ : 1
arge rock slabs extending back into hill and earth	1 : 1	1½ : 1	¾ : 1	1½ : 1	¾ : 1	1½ : 1
isintegrated rock and shale	½ : 1	1½ : 1	½ : 1	1½ : 1	½ : 1	1¼ : 1
olid rock	¼ : 1	1 : 1	¼ : 1	1 : 1	¼ : 1	1 : 1

Examples of Typical Sections High Class Roads.—The following pical sections give an idea of the trend of present practice:

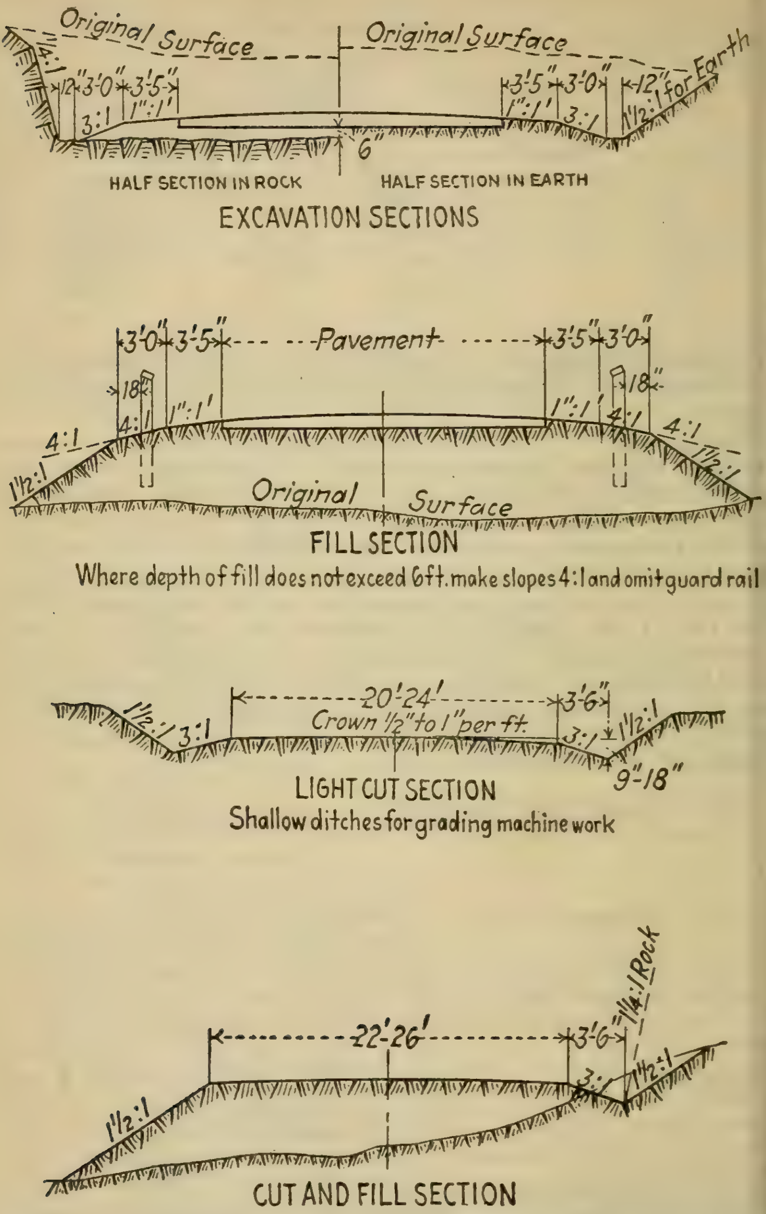


Fig. 28.—Earth road sections. U. S. Bureau Public Roads (1925).

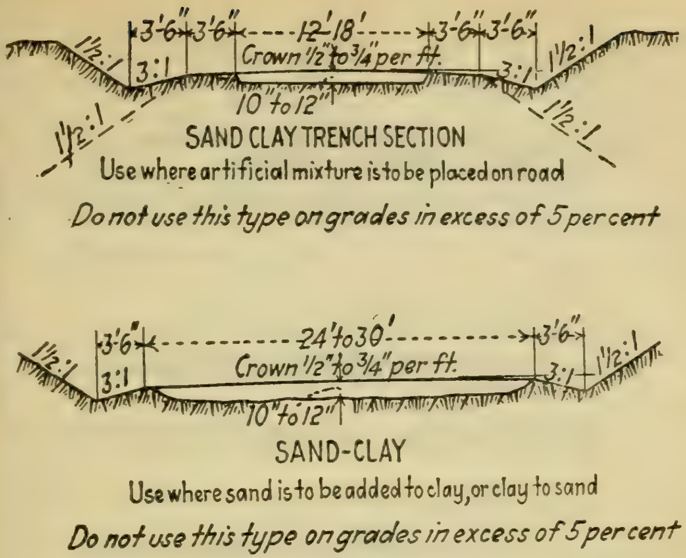
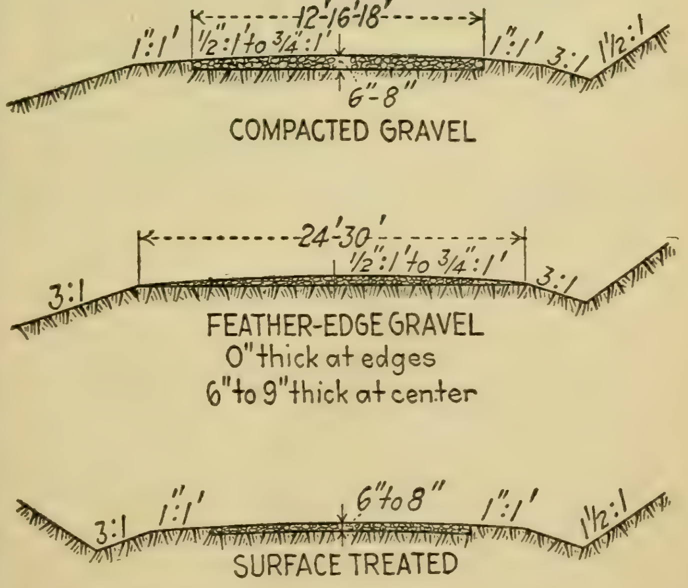


FIG. 28.—Sand clay roads.



[F]IG. 28.—Gravel roads. U. S. Bureau Public Roads (1925).

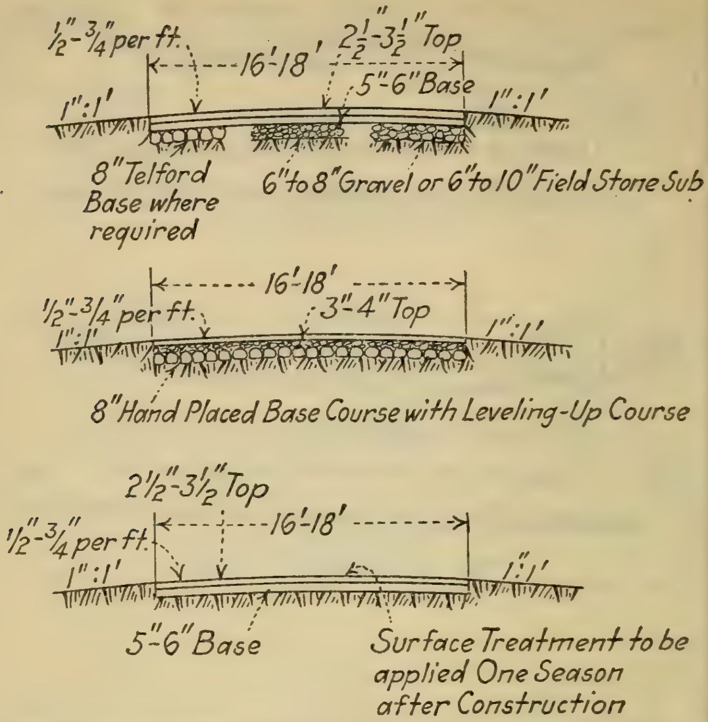


FIG. 28.—Waterbound macadam. U. S. Bureau Public Ro(1925).

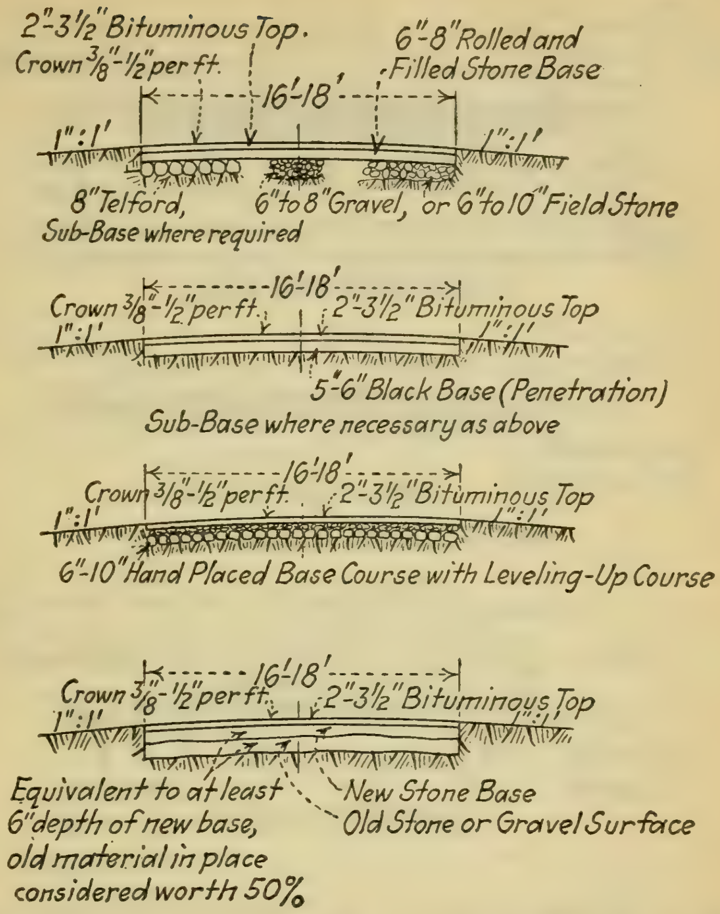


FIG. 28.—Bituminous macadam. U. S. Bureau Public Roads (1925).

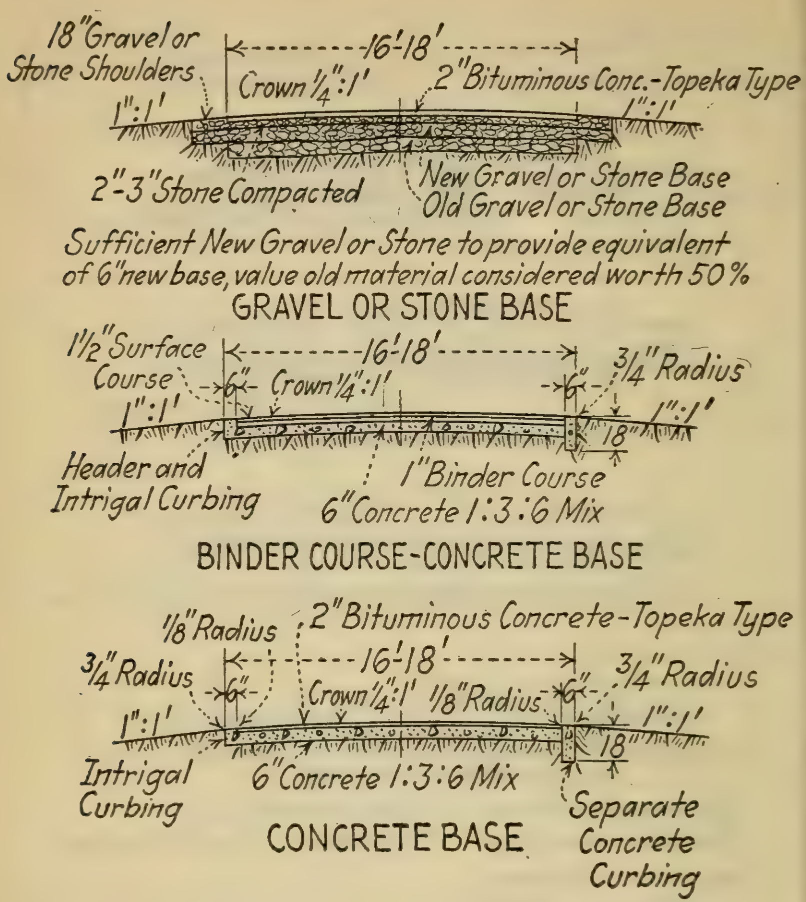


FIG. 28.—Bituminous concrete. U. S. Bureau Public Roads (1925).

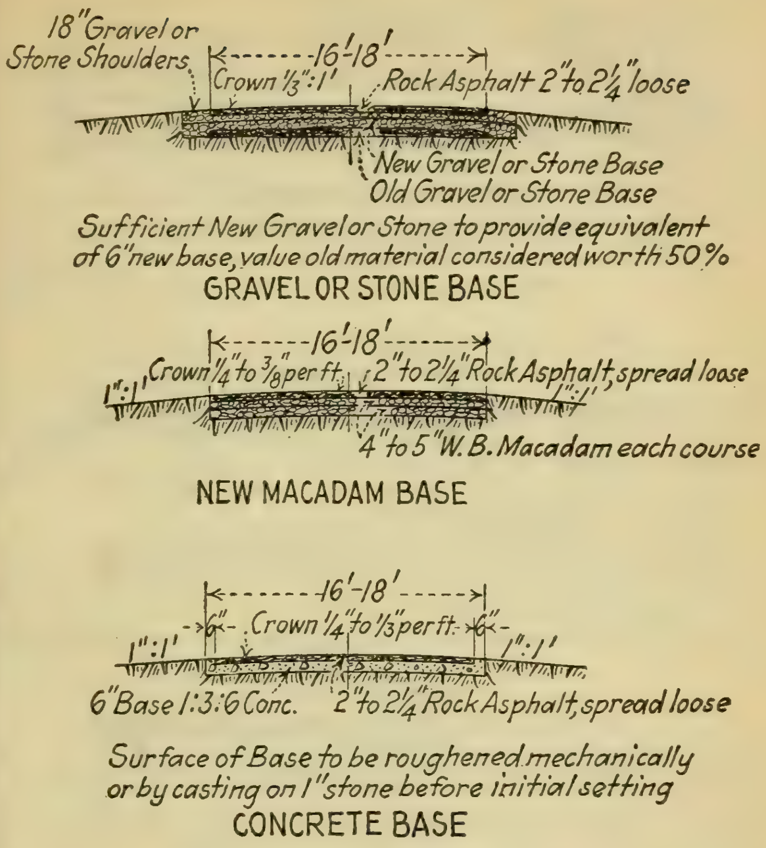


FIG. 28.—Rock asphalt. U. S. Bureau Public Roads (1925).

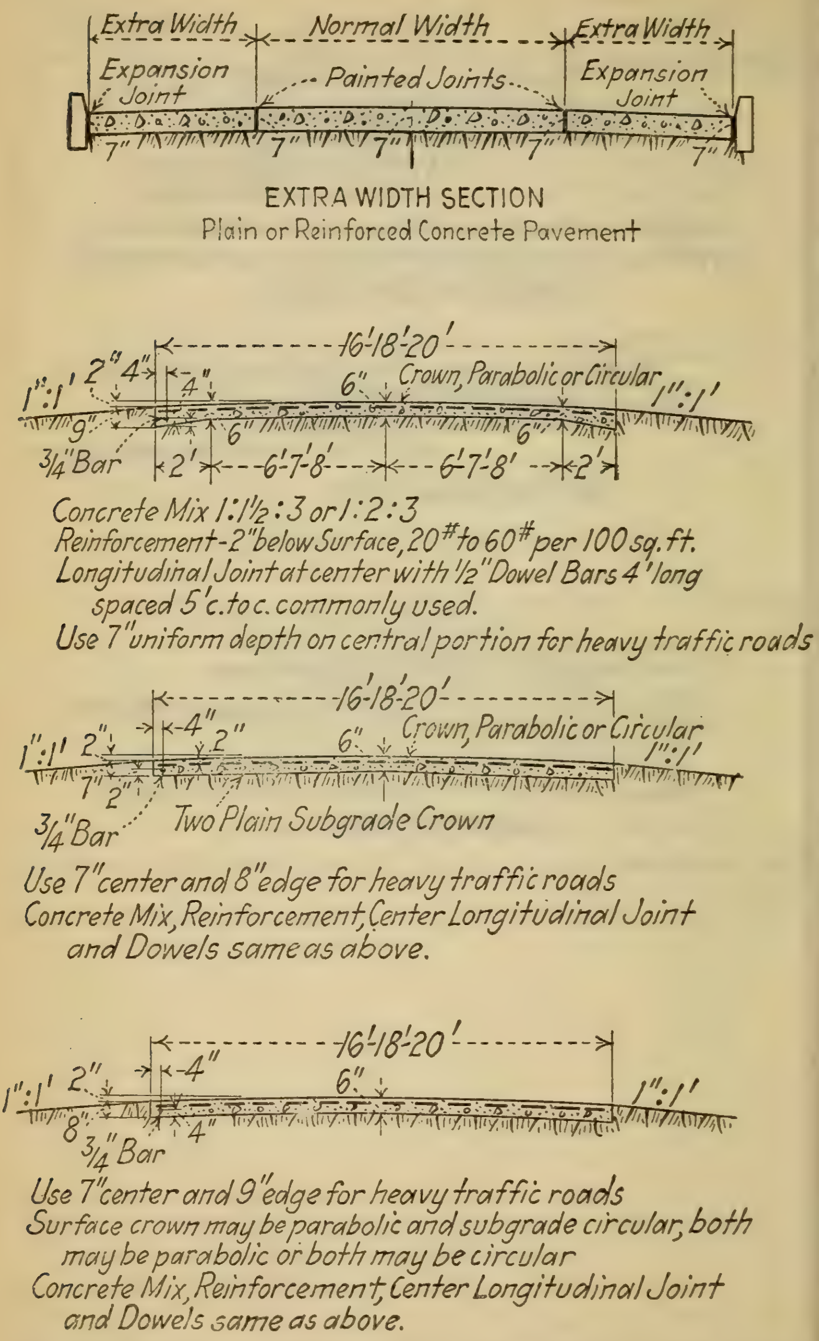


FIG. 28.—Cement concrete. U. S. Bureau Public Roads (1925).

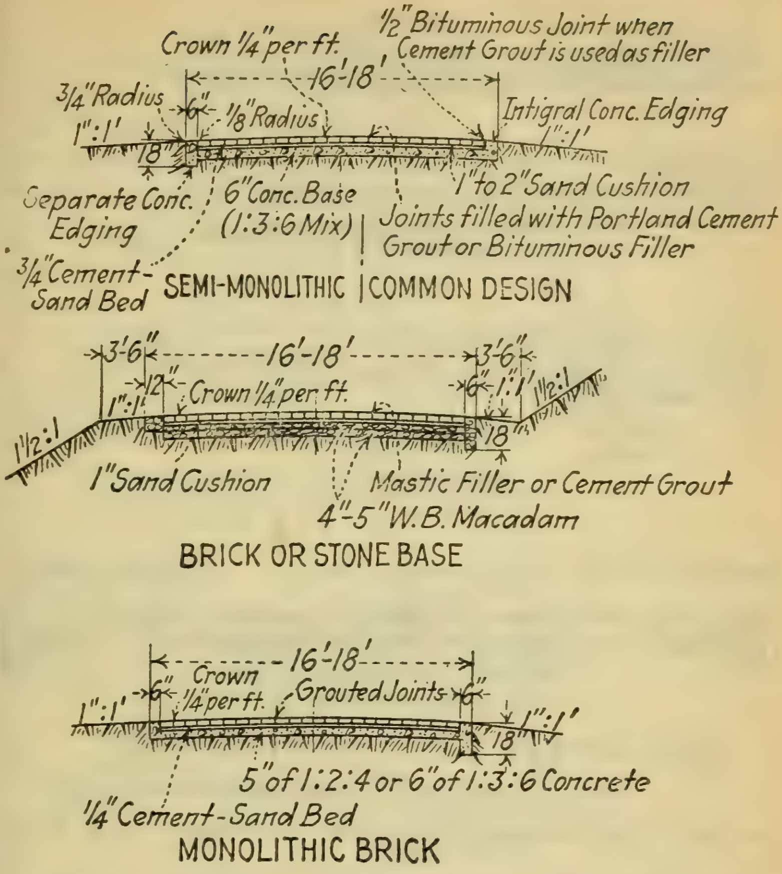


FIG. 28.—Brick. U. S. Bureau Public Roads (1925).

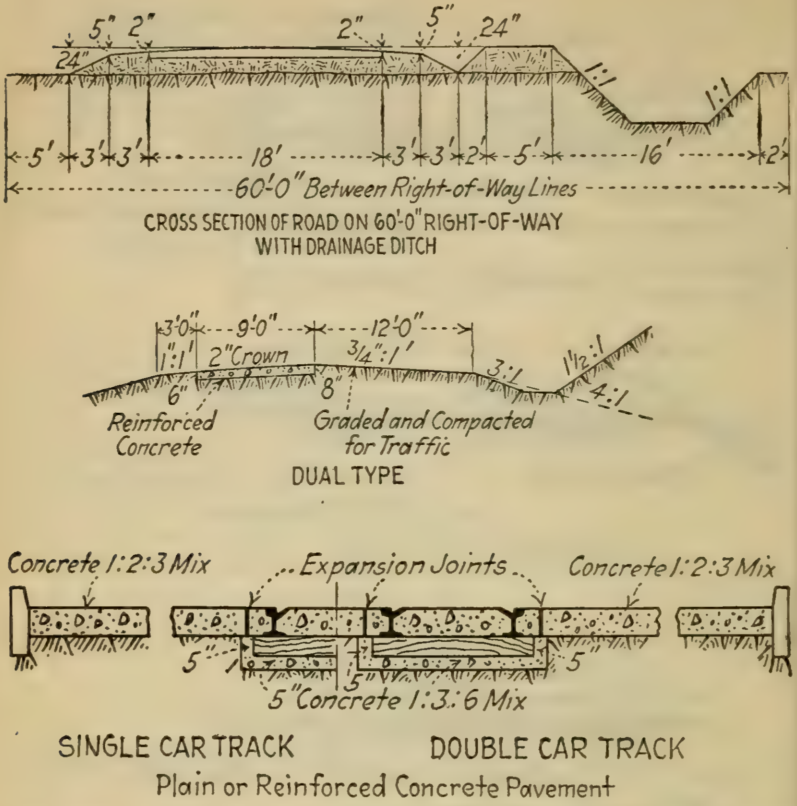


FIG. 28.—Miscellaneous sections. U. S. Bureau Public Roads (1925).

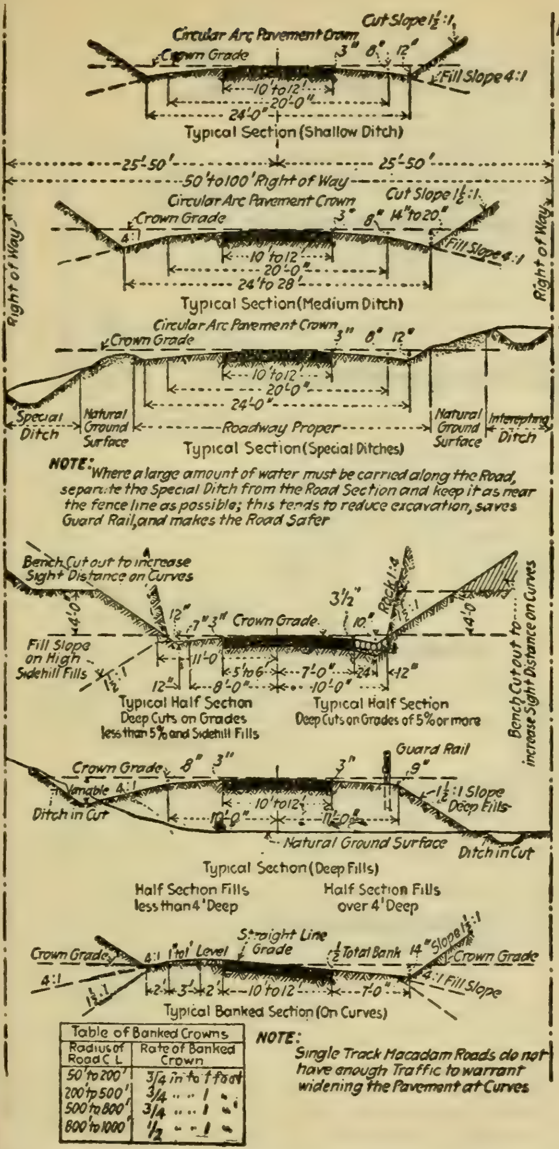


FIG. 29*A*.—Single track macadam or gravel roads (suitable for roads carrying up to about 300 vehicles per day). Typical sections.

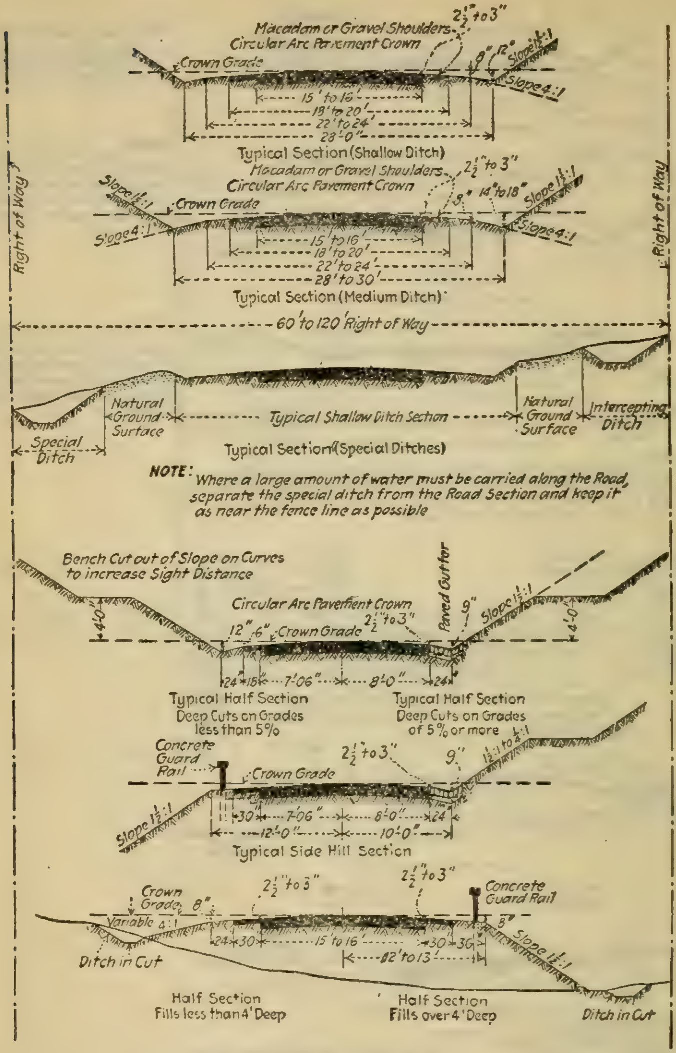
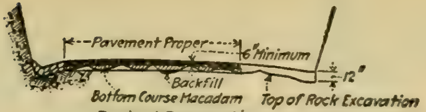


Fig. 29*B*.—Double track macadam roads. Suitable for local service or secondary State Roads carrying from 300 to 2000 vehicles per day (12 hour count in summer). Typical sections.

Note.—Use 7 ft. shoulder for traffic over 1500 daily average to permit parking off the pavement.

Right of Way Line

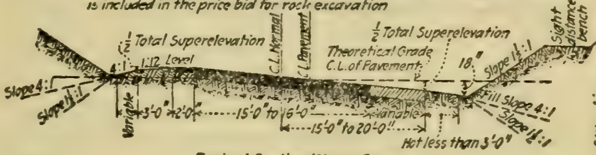


Typical Rock Section

NOTES:

Rock excavation will be paid for to an elevation 12 inches below the surface of the finished road and no rock excavation will be paid for below this elevation or outside of the neat side slopes shown on the plans.

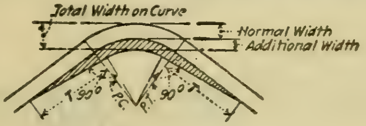
No part of the solid rock shall be closer than 6 inches to the top of the finished section. All depressions under the pavement proper lower than the bottom of the bottom course of the pavement shall be backfilled with stone chips, filled with sand or gravel, and rolled or tamped until firm and hard. This backfill is included in the price bid for rock excavation.



Typical Section (Sharp Curves)

Right of Way Line

Table of Rate of Superelevation	
Radius of Road Center Line in Feet	Rate of Superelevation
50 - 200	3/4 in to 1 foot
200 - 500	3/4 " " 1 "
500 - 800	3/4 " " 1 "
800 - 1000	1/2 " " 1 "



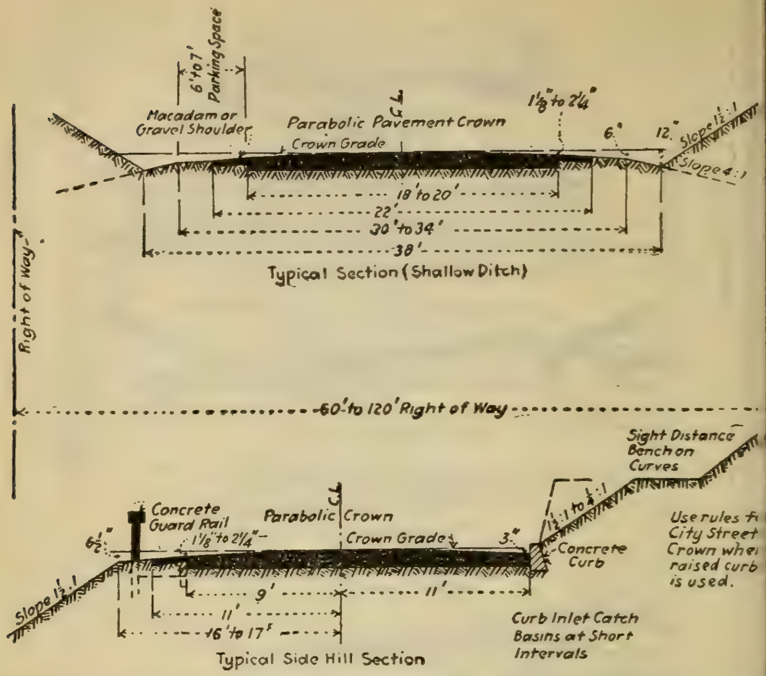
Pavement Widening Layout

Table of Pavement Widening		
Radius of Road Center Line in Feet	Total Width Pavement on Curves	"T" Feet
50 Feet	29 Feet	100
75 "	25 "	100
100 "	23 "	100
200 "	21 "	90
300 "	20 "	80
400 "	20 "	80
500 "	19 "	70
600 "	18 "	50

NOTE: Use normal Pavement Width on Curves having a radius of more than 600 feet

Table of Recommended Total Depth of Macadam Pavements on Different Soils			
Pavement in Cut or Fill	Soils: Sand or Gravel	Loam	Heavy Clay or Quicksand
In Cut	8"	9" to 12"	15" to 24"
On Fills less than 1 ft deep	8"	9" to 12"	15" to 24"
" " 1 ft to 3 ft "	8"	9"	12" to 15"
" " over 3 ft "	8"	8"	9"

FIG. 29B.—Double track macadam roads. Typical sections.



TYPICAL MEDIUM DITCH SECTION
" SPECIAL " "
" FILL SECTION
" BANKED "
} Similar to Fig. 29*B* except t the Overall Width dimensi are 6′ to 8′ greater than gi in Fig. 29*B*

ROCK EXCAVATION: Method of Payment similar to Fig. 29*B* exc that none of the Solid Rock shall project ab the bottom of the Pavement Base

NOTE: For thickness of Pavements and Design of Pavement Base : Surfacing See Chapter VI

Fig. 29*C*.—Special sections rigid pavement roads (roads carry over 2000 vehicles per day. Typical sections.

STANDARD GRADING SECTION, ILLUSTRATING METHOD OF DESIGNATING ROADWAY WIDTH

Standard roadway width to be designated as width in thorough cut, dimension "A" in the table. Reference to a standard roadway width will imply the corresponding dimensions as shown in the table.

STANDARD ROADWAY WIDTHS	CUT A	SIDE HILL B	FILL C	1/2 A	1/2 C
20'	20'	21'	22'	10'	11'
24'	24'	25'	26'	12'	13'
28'	28'	29'	30'	14'	15'
30'	30'	31'	32'	15'	16'
40'	40'	41'	42'	20'	21'

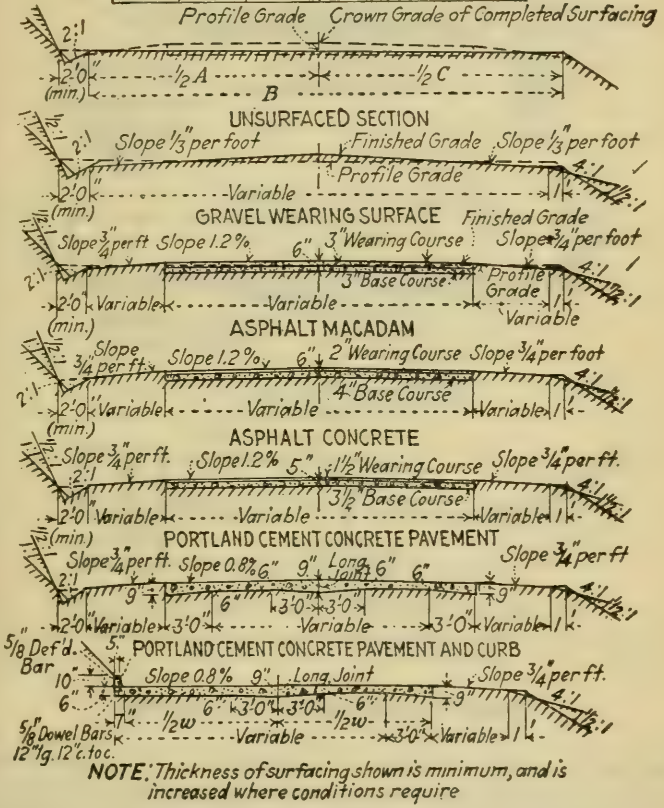


FIG. 28A.—California standard road sections (1925). (State roads.)

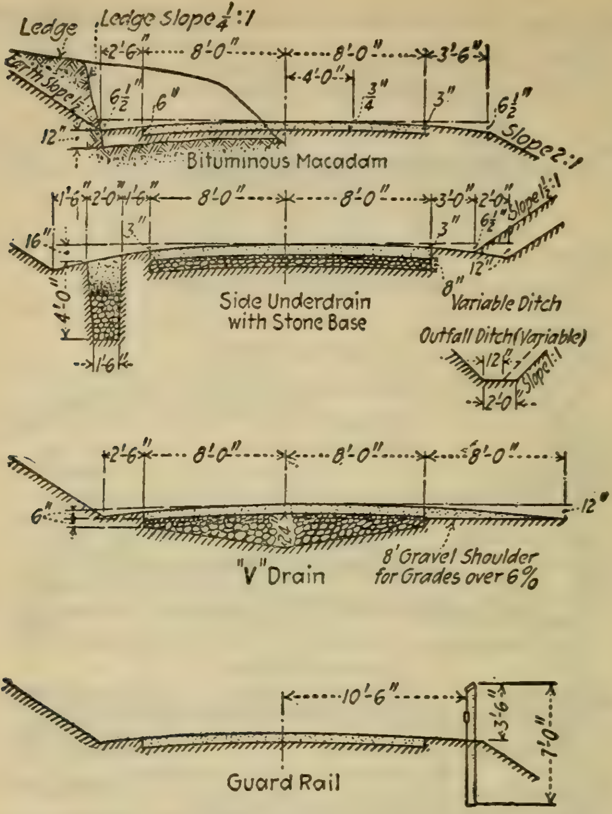


FIG. 28*B*.—State of Maine standards (1925).

MOUNTAIN-ROAD SECTIONS

Discussion.—The desirable requirements for mountain-ro sections are the same as for roads previously discussed, but on ste side-hill work the width of grading used for ordinary topograp would be prohibitive in cost. As most of these roads are natu soil roads, the crown is the only element of the section not cove in the previous discussion. For the gravel or stony material usua encountered $\frac{1}{3}''$ to $1'$ is generally satisfactory. For sand or hea soils $\frac{1}{2}''$ or $\frac{3}{4}''$ to $1'$ is better practice. The old idea that cro should be increased on steep grades has been abandoned for, wh that expedient undoubtedly helped the drainage, it caused more convenience to traffic than it was worth. In many cases present pr tice decreases the crown on steep grades to give better vehicle co trol. Crowns on mountain roads are also affected by the abse of guard rail or other safety provisions. The ordinary symmetri crown is used where wall or guard rail protects the dangerous o

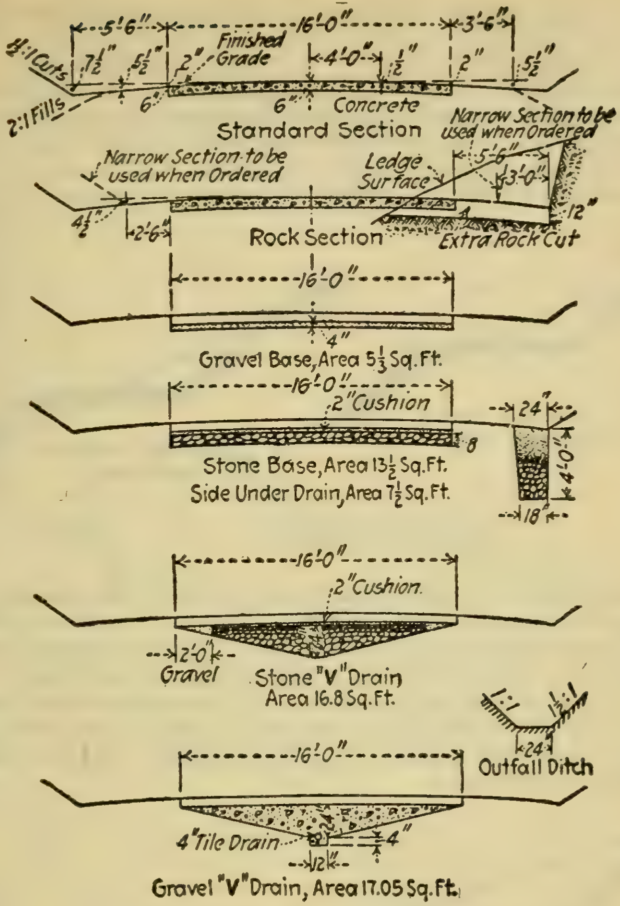


FIG. 28*B*.—(*Continued.*)

side slope, but on many roads so much rail would be needed that it s prohibitive in cost, and where it cannot be used the road is tipped one way in a continuous slant toward the hill so that if a machine skids it will slide in against the cut slope. This kind of section is not so comfortable to ride as the ordinary crown, but if the surface s at all greasy the element of increased safety outweighs any minor nconvenience of side tilt.

Effect of Width on Cost.—The width of section has more effect on cost than any other part of the design. On a new side-hill ocation the relation of width to cost can be roughly established. It will, of course, vary for different side slopes of the hill and different cut slopes of the excavation, but the relation will be approximately as follows, for balanced sections (Table 128, p. 786).

EXCAVATION PER MILE. 25° SIDE-HILL SLOPE

1 : 1 slope in cut. 1½ : 1 slope in fill
(S-8) 10′ width (ditch to outside of shoulder) 4,300 cu. yd. per mil
(S-10) 12′ width (ditch to outside of shoulder) 6,100 cu. yd. per mil
(S-14) 16′ width (ditch to outside of shoulder) 10,200 cu. yd. per mil
(S-16) 18′ width (ditch to outside of shoulder) 12,800 cu. yd. per mil
(S-18) 20′ width (ditch to outside of shoulder) 15,400 cu. yd. per mil

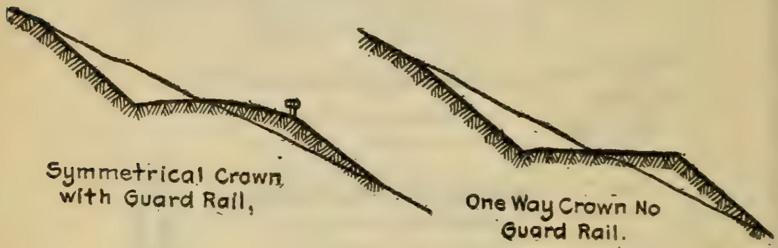


FIG. 30.

In general, a 20′ width requires about three and one-half time as much excavation as a 10′ width. The relative cost of differen widths is also affected by the amount of rock excavation, which i generally much greater for the wider widths. This depends on th depth of soil overlying the rock. This element affects the cos so much that in certain cases it has been found cheaper to build tw separate single-track roads for short distances rather than on double-track highway.

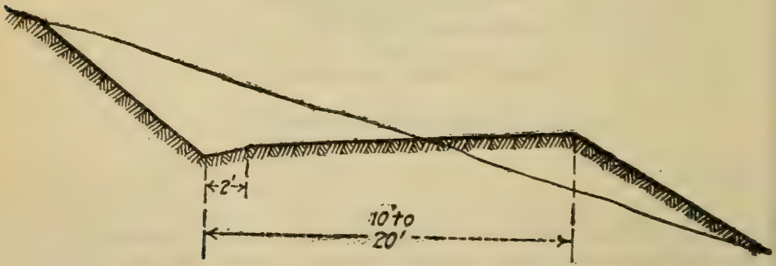


FIG. 31.

Mountain roads are classed roughly as double track or single track, meaning the same as for railroad work, a double line of traffic or a single line with turnouts to allow passing. As each foot of extra width is costly, it is important to determine the minimum width of grading that will serve the purpose for these two classifications.

Minimum Width Side-hill Section.—If the roadbed is benched out of solid rock, a narrower width will serve as the entire width is firm and stable. If the section is a balanced section part in cut

and part in fill, it must be wider, as embankments on steep slopes are liable to settle, slide, or wash out and it is not safe to drive so closely to the edge as in the first case. The amount of road "in solid" is therefore the prime requisite and "feet in solid" is often used as the specification for contract road jobs where engineering design

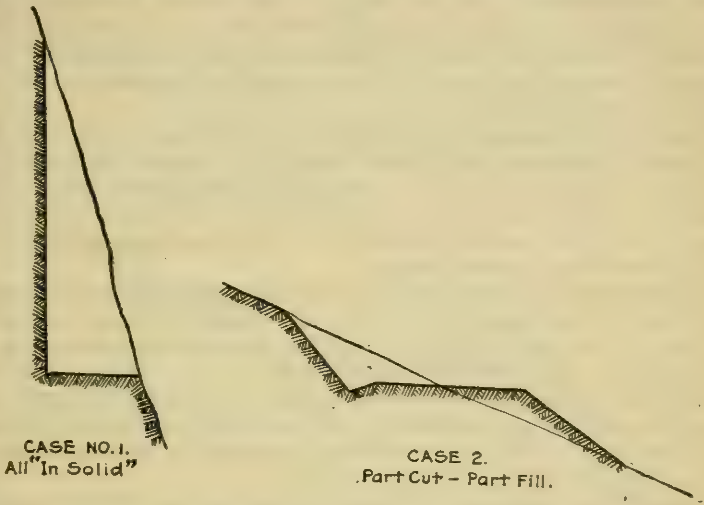


FIG. 32.

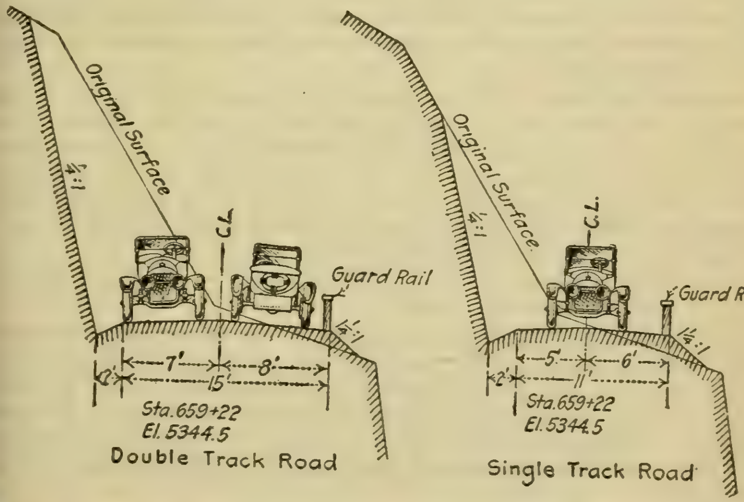


FIG. 33.—Single and double track roads.

is not used. Present practice favors a minimum single track, total grading width of 10′ in rock or where the outer embankment is sustained by a retaining wall and a total width of 12′ for the ordinary balanced section in earth. Balanced sections are generally

used up to 30° side slopes and beyond that toe walls or retaining walls are necessary for earth sections. For a 30° side slope a total grading width of 12′ results in approximately 7 to 8′ in solid cut. A double-track section requires a minimum total grading width of 14′ in rock or wall sections and 16′ in balanced earth section, which gives approximately 10′ in solid. These same limiting widths apply to turnout sections on single-track roads. Where guard rail is used 1′ should be added to these widths. These widths are, however, very skimpy, and if the money is available at least 2′ additional should be used.

Turnouts.—On single-track roads turnouts are constructed at sufficiently frequent intervals so that drivers can see between them and there will be no danger of meeting at impassable spots. This generally requires from 5 to 10 to the mile. The minimum satisfactory length of turnout is about 60′ and the grade should be as easy as possible at these points.

Fill Sections.—Through fill sections must be constructed wider than side-hill sections, as the sides are bound to slough off under weather action and all the elements of wear tend to decrease the width; 14′ is considered the minimum width for a single-track road and 20′ the minimum for a double-track. A symmetrical crown is advisable on fills even on curves. Where guard rail is used, increase these widths 2′. These sections occur on only a small per cent of the length of mountain roads.

Through Cut Sections.—These sections are rare in occurrence; the minimum width, ditch to ditch, for single-track roads can be considered as 12′ and for double-track 18′. The use of minimum widths for either through cut or fill sections on mountain roads has small effect on cost, and for that reason more liberality in their widths is allowable.

Turnpike Sections.—Where the natural ground cross-slope is less than 5°, turnpiking is the usual construction and the difference in cost of a single or double track is so small that it is not worth considering. For this class of section a minimum of 22′ between ditches will apply to any road, and a width of 24′ is generally used.

Selection of Section.—Plate 35 (pp. 166 to 171), illustrates typical mountain-road sections, pioneer districts.

The turnpike section is used up to natural ground side slopes of 5° for continuous balanced work.

The side-hill sections are used above 5° for continuous balanced work. The one-way crown is used on all single-track side-hill sections where guard rail is lacking. The one-way crown is used on unprotected double-track roads where the side slope is greater than 15°. The symmetrical crown is used on protected double-track roads and on unprotected sections where the side slope is less than 15°.

Through cut and fill sections are used where required by the profile.

Superelevation is used on curves, but rarely on high through fills. The ditch on the upper side of a superelevated through cut section can be omitted if the cut is short.

Cut and fill slopes depend on the natural material and climate ıd were discussed on page 144. There is too much tendency to ;e steep slopes to save on construction cost, although excessively ıt slopes are not necessary or advised, it being cheaper to take care minor slides by maintenance (for effect of cut slopes, see Table :8, p. 786).

Wall Sections.—These sections are used where the natural hill ›pe is practically as steep or steeper than the stable embankment ›pe. Toe or retaining walls are necessary for earth embankments here the natural slope exceeds approximately 30° and for rock ls where the natural slope exceeds approximately 40°. Wall :tails are described in Chapters X and XII. Surcharged breast ılls are to be avoided if possible.

FIG. 34.

Intercepting Ditches.—Where considerable water runs down the ›hill slope, intercepting ditches are used to protect the cut slope ıd relieve the road ditch of excess water. These ditches discharge the nearest cross-culvert and are an important part of the design.

Bench Sections.—Bench sections are used in rock ledge work ɛe sec. S-10, Plate 35, and Table 128, p. 786).

STREET SECTIONS

Widths.—This book is primarily concerned with the design of ral highways, but in connection with rural improved highways is often necessary to design short stretches of village or city street ıvements as connecting links on such systems, and proper widths pavements and sidewalks on streets become an element in the :signs to be handled. City-street layouts and widths are big bjects, covering a wide range from unimportant resident streets pleasure boulevards and congested main streets. The subject is :ll covered by works by Robinson, Lewis, Blanchard, Agg, etc., ıd for special problems readers are referred to such works.

Connecting links in state highway systems through villages :nerally refer to main residential or business streets of villages or ıall cities. For these conditions, central parking spaces are rely desirable, and the layout is the common one of roadway with le lawns or wide sidewalks from the curb to the street line.

For residential streets where occasional parking parallel to the rb prevails, a width of paved street of 30 to 32′ between curbs a satisfactory minimum on state route connecting links through

(text continued on page 174.)

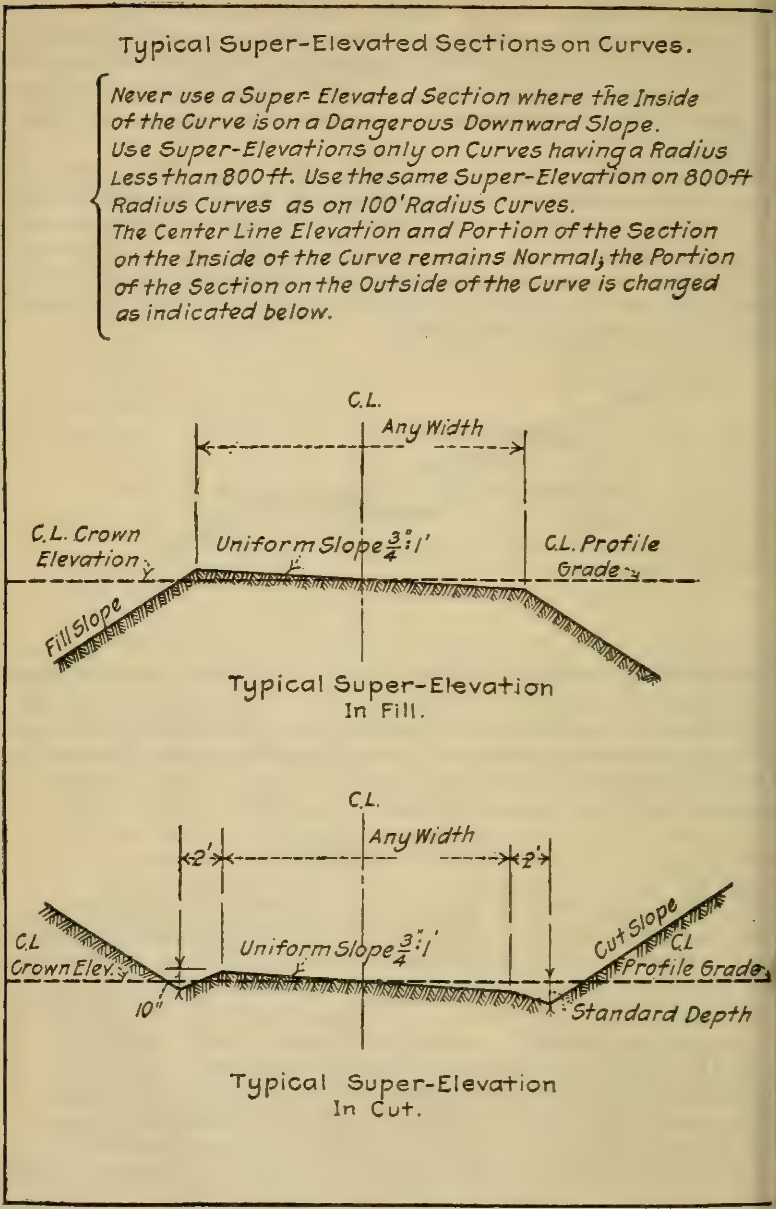


FIG. 35.—Pioneer mountain roads.

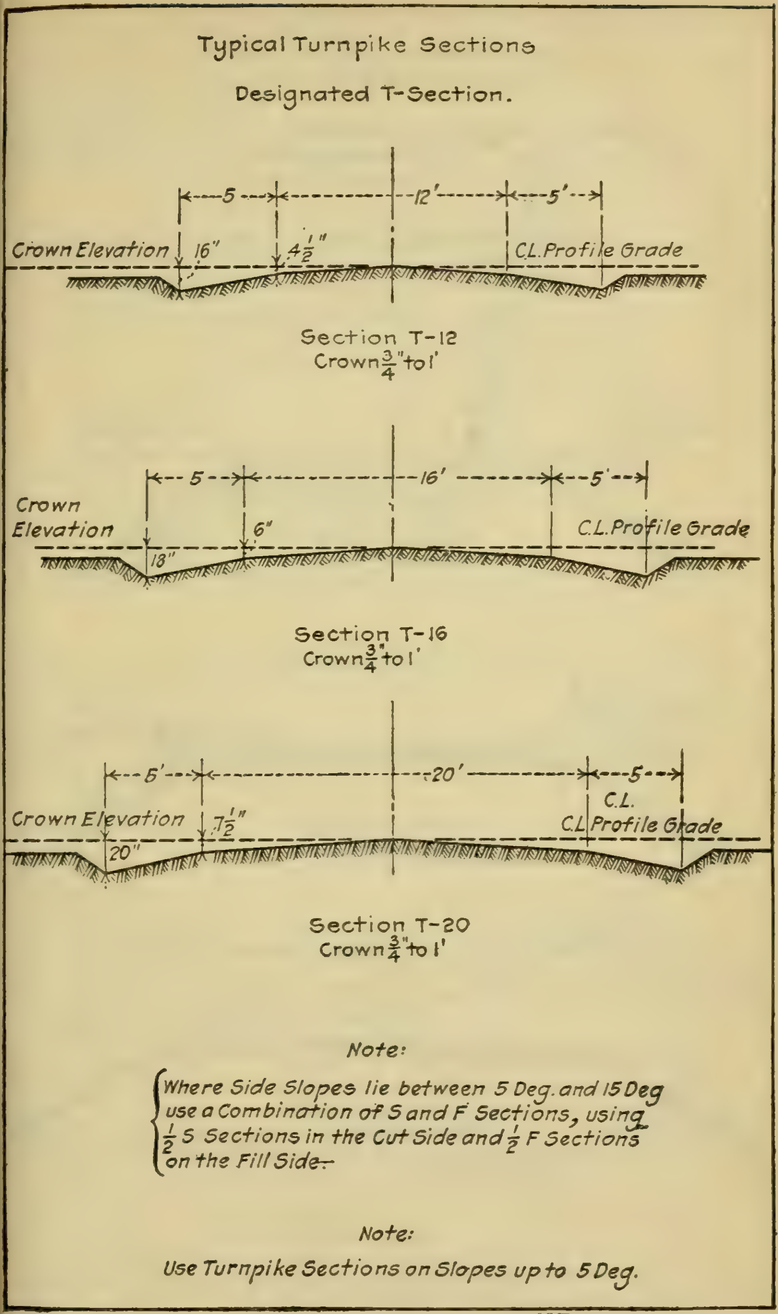


FIG. 35.—Pioneer mountain roads (*continued*).

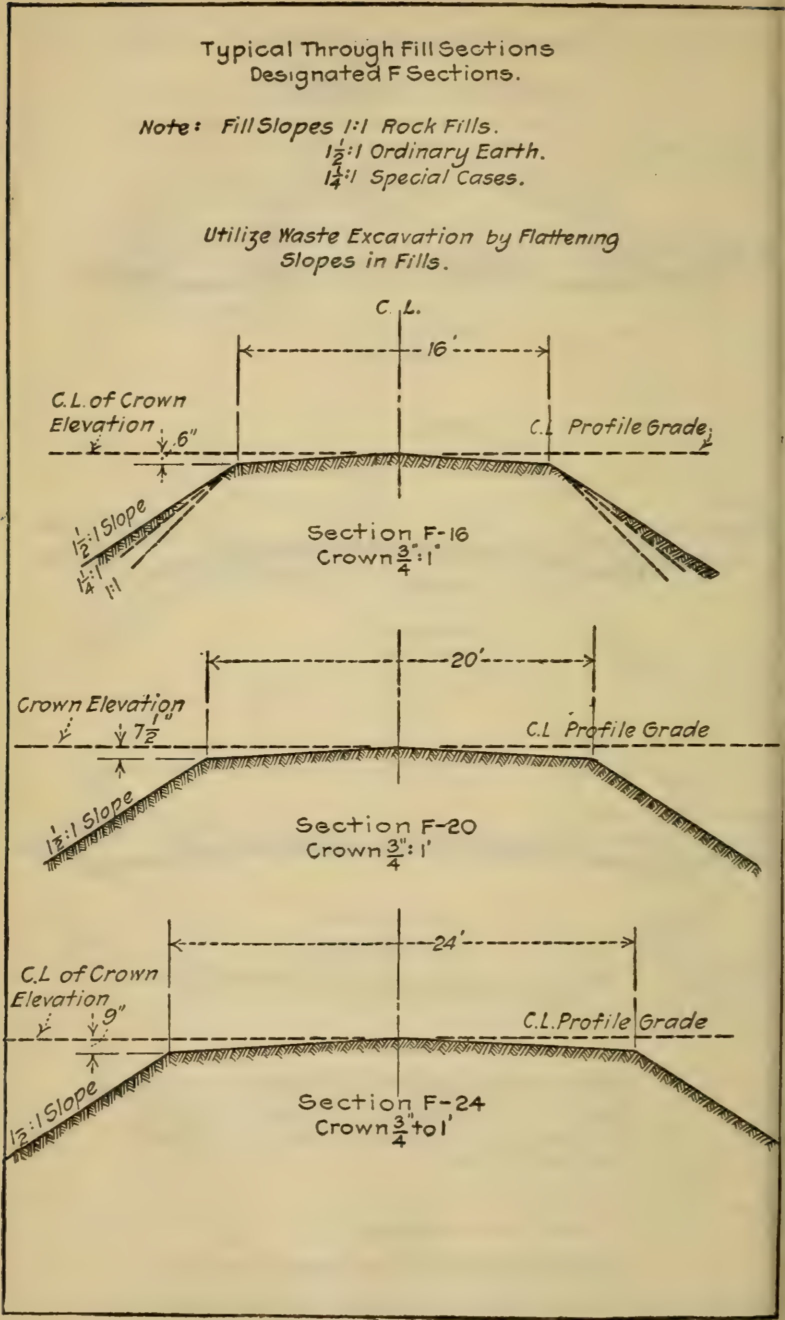


FIG. 35.—Pioneer mountain roads (*continued*).

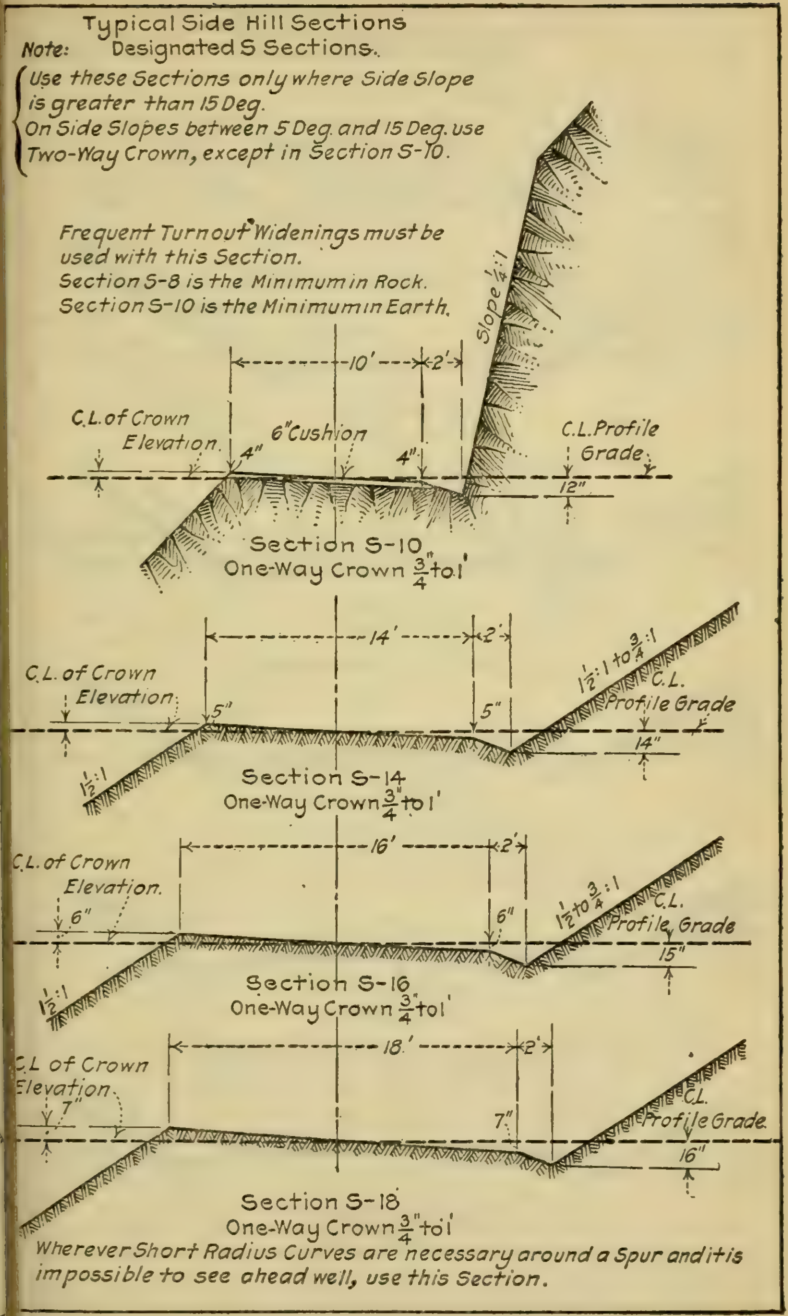


FIG. 35.—Pioneer mountain roads (*continued*).

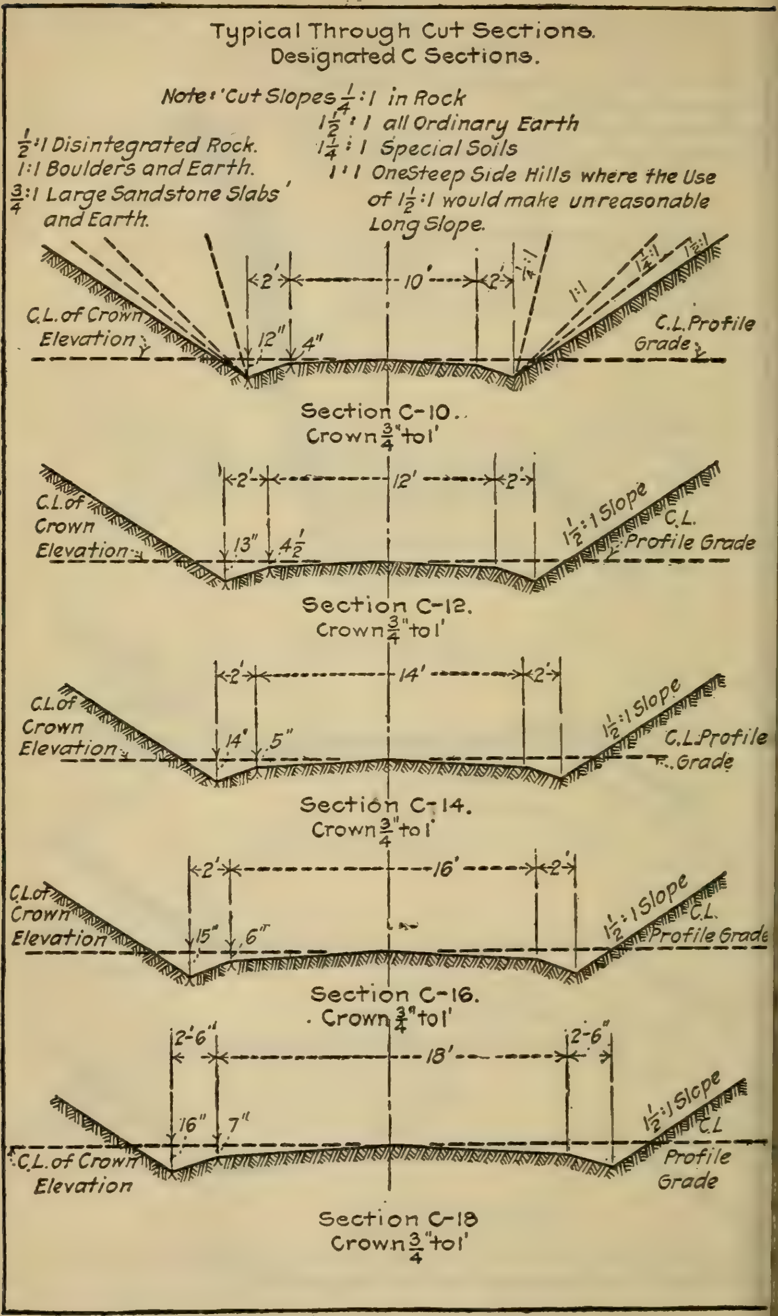


Fig. 35.—Pioneer mountain roads (*continued*).

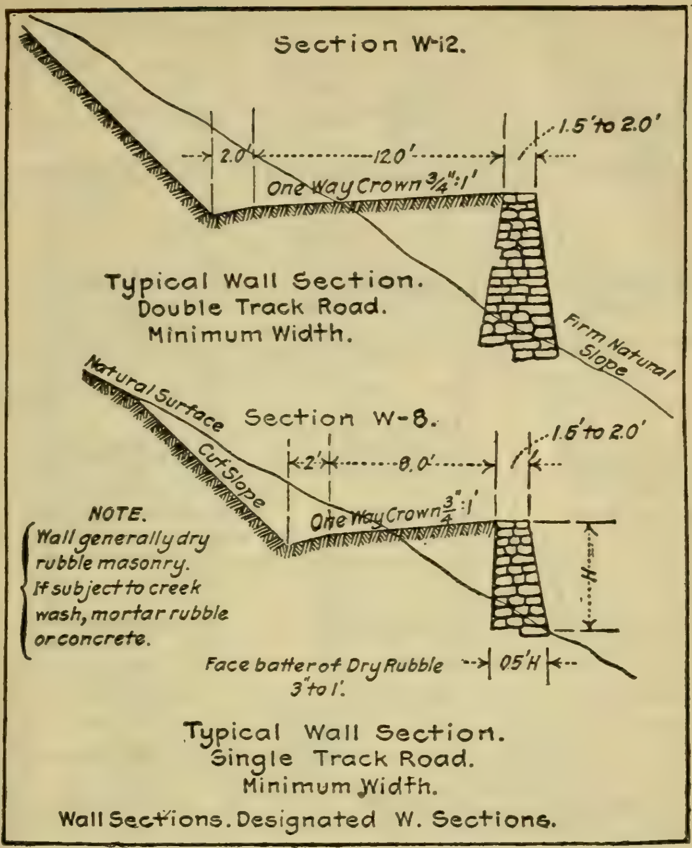


FIG. 35.—Pioneer mountain roads (*continued*).

STREET WIDTHS

Chicago Regional Planning Commission recommends widths of aving as follows:

	Feet
A. Lane for moving traffic	10
B. Lane for parking parallel with curb	8
C. Lane for parking at angle with curb	18

For single-family residential streets 66-ft. right of way and 26-ft. ıvement width.

For main residential streets 66-ft. right of way and 36-ft. paving idth (two moving lanes and two parking lanes).

For business streets 80- and 100-ft. right of way with 56- or -ft. paving for four or six moving lanes and two parking lanes.

Author's Note: For a moving lane where vehicles are largely ıssenger autos 9 ft. is ample; 10 ft. is required for trucks and ısses.

FIG. 36.—Street widths. City Planning Commission, Rocheste N. Y., 1926.

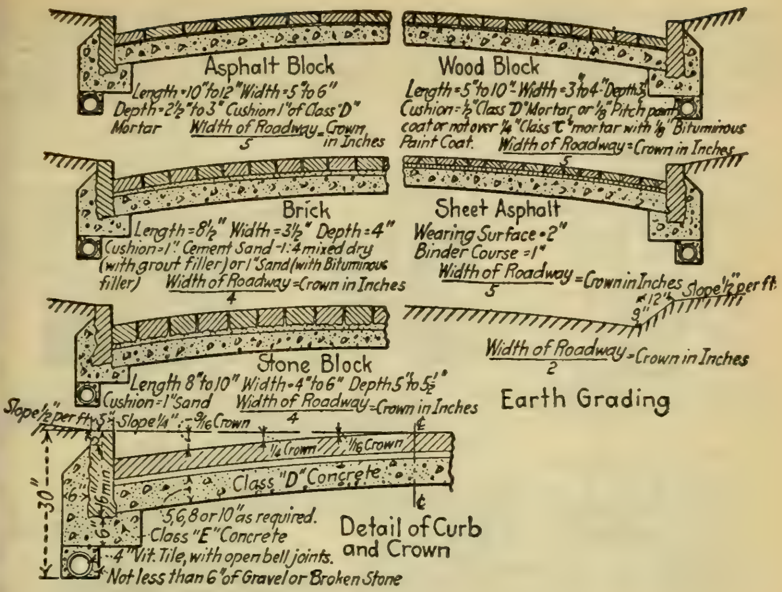


FIG. 37.—Rochester street crowns

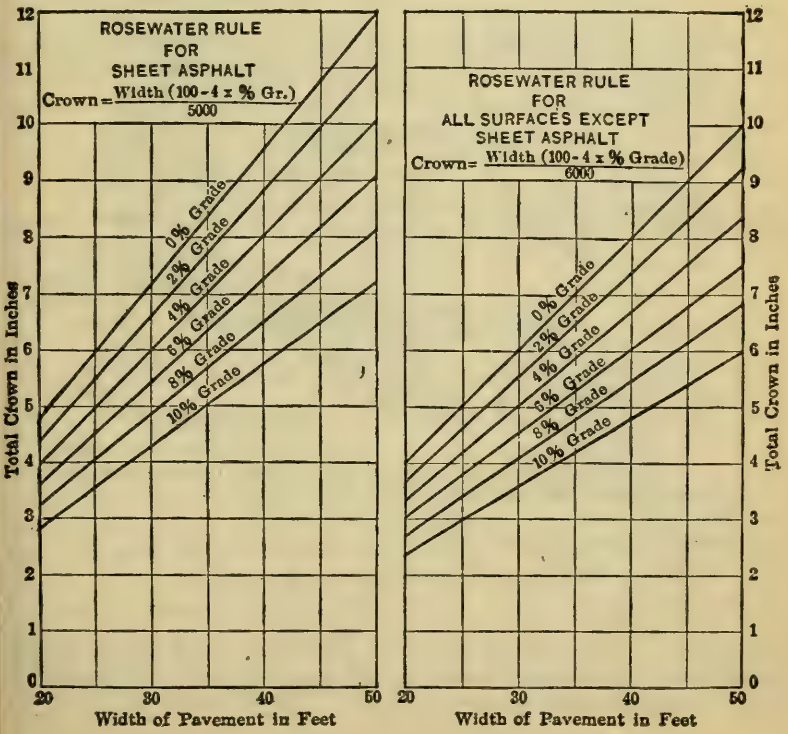


FIG. 38.—City street crowns.

villages where there are no street car tracks. Where double car tracks occur it is customary to increase the minimum to 36′, although this width does not give as great freedom of movement and a width of 50′ is advisable if the total width between street lines

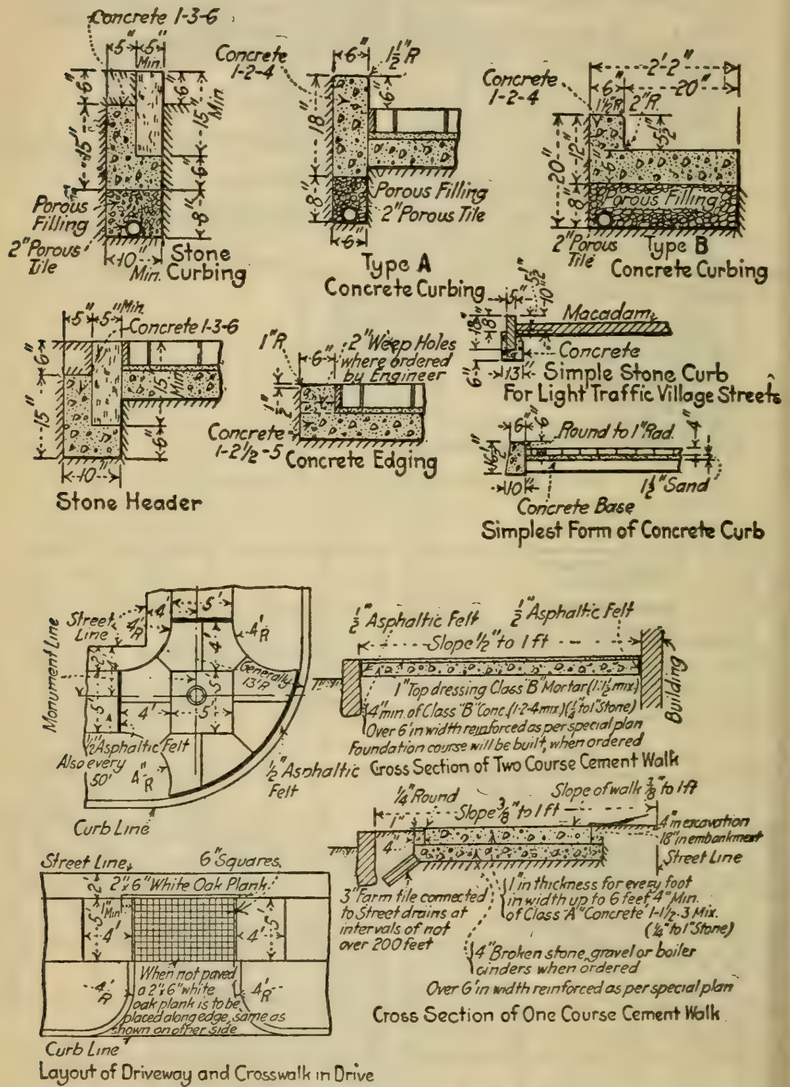


FIG. 39.—Sidewalk and curb details.

will permit. Sidewalks 5′ wide with a variable width of ornamental grass, tree, or shrubbery parking with a minimum cross-slope of ¼ to ⅜″ per foot will serve very well. Excessive pavement widths

are to be avoided on residential streets and wide side parking adds to the pleasing appearance of the street.

In business sections a minimum width of 50 and preferably 60′ between curbs is desirable where there are no car tracks. Sidewalks from curb building line should be at least 12′ if the total width of the street permits. For wide business streets it is rarely necessary to make the sidewalk more than 18′, the pavement taking up the balance of the space. Where street car tracks occur, it is desirable to make the pavement as wide as possible without reducing the sidewalk width below the 12′ limit.

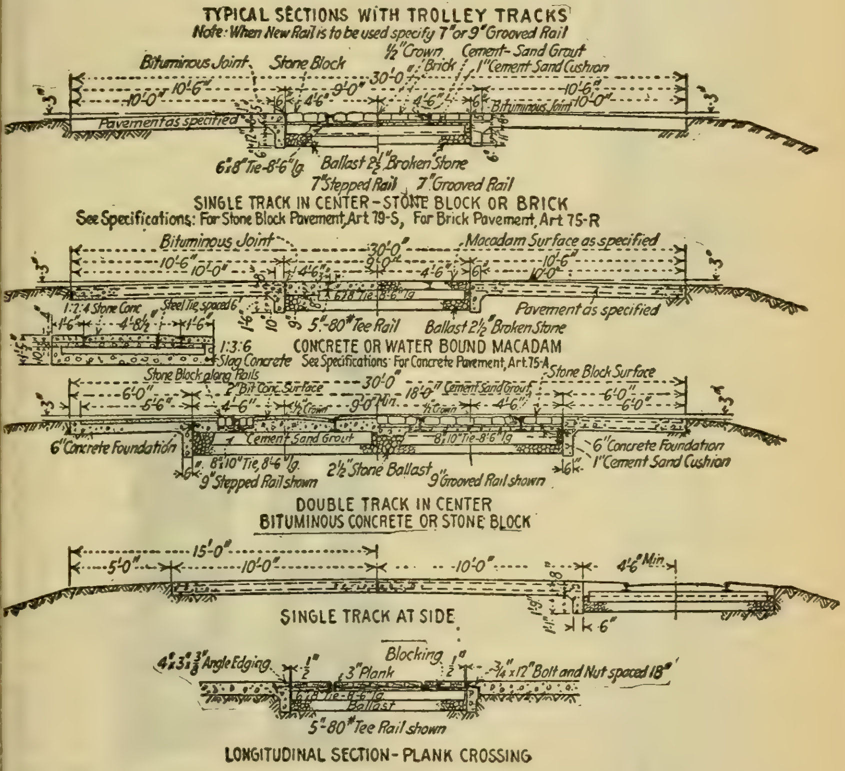
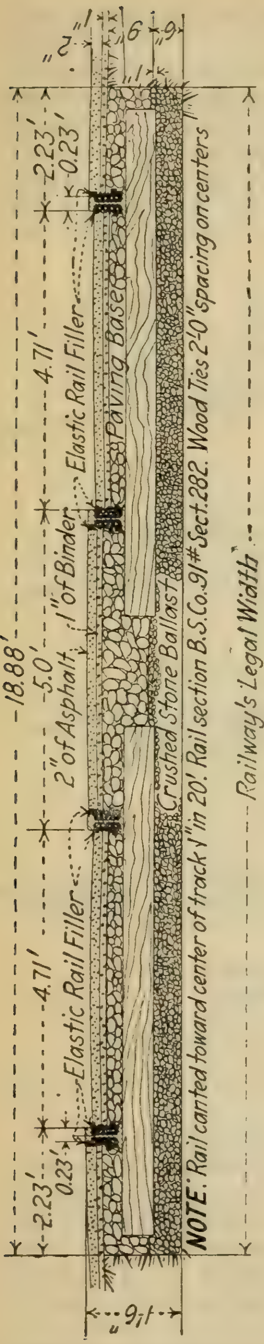


FIG. 40.—Typical car track sections (State of New Jersey, 1922).

Figure 36 shows good typical street-paving widths.

Crowns.—On curbed streets, the crown should be more than on rural highways to concentrate flow into a narrow gutter area, and also because a flat crown does not look so well as a moderately high crown. Figures 37 and 38 show good standard practice which looks well, rides easily and drains well. Circular arc or parabolic crown curves are recommended (see p. 956 for method of figuring crown ordinates).

Sidewalks.—Figure 39 shows the details of satisfactory sidewalk construction. Cross-slopes of ¼″ per foot are satisfactory for concrete walks and ½″ per foot for brick walks.



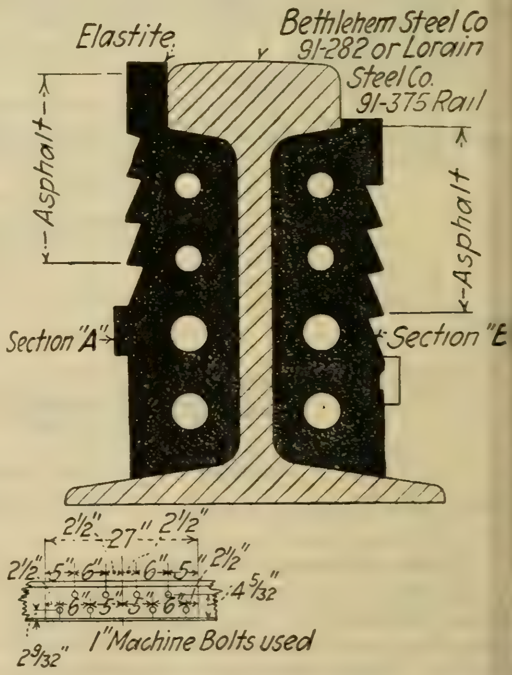


FIG. 41.—Street car track details, Rochester, N. Y. (1926).

Car Tracks.—Figures 40 and 41 show good typical car track onstruction.

Incidentals.—For details of curbs, catch basins, manholes, ghting posts, etc., see Chap. X (pp. 685 to 696).

RIGHT-OF-WAY AND CLEARING WIDTHS

The width of right of way is determined by required grading idths, by required clearing widths, by possible future widening of ie grading, and by a minimum sight distance where buildings may e erected directly on the road boundary or where a heavy stand of rush or trees grows on the land back of the road boundary. While is desirable to provide sufficient width for all the requirements of ie future, the use of a needless width results in waste land which ight better be utilized for farming or building purposes. There ave been cases of rights of way 500′ wide in flat country, which re merely ridiculous.

The ordinary double-track improved road section varies from 4 to 36′ ditch to ditch. The cut and fill slopes back of the ditch

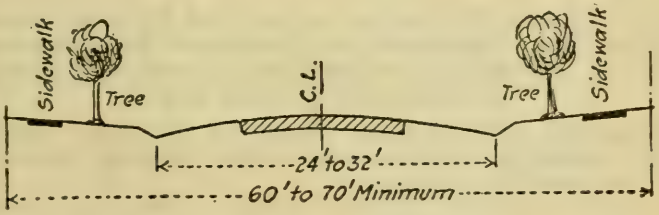


FIG. 42.—Future road section.

ne rarely take up more than 10′ in ordinary topography and xperience indicates that a 50′ width of right of way will, as a rule, e satisfactory as far as the grading of the ordinary rural road is oncerned. Practically all engineers are agreed that tree planting nd sidepaths for pedestrians are only a matter of time, and that an llowance for improvements of this kind is reasonable. Such an llowance would naturally increase the normal right-of-way width or the usual local service road to approximately 60′.

On state and national routes where four lines of traffic are anticiated a normal width of 80′ ought to serve satisfactorily except as nodified for deep cuts and fills, sight distance on sharp curves, and learing widths.

Modifications for deep cuts and high fills show up on the crossections. Modifications for sight distance can be worked up iagrammatically for each case, but in order to give some idea of the pproximate increase in right-of-way widths for sharp curves the ollowing tables are inserted.

TABLE 41.—TABLE OF DISTANCE BETWEEN CENTER LINE OF ROA[D] AND RIGHT-OF-WAY LINE ON THE INSIDE OF THE CURVE TO PERMIT CERTAIN SPECIFIED SIGHT DISTANCES, ASSUMING THAT THE LINE OF SIGHT IS NOT OBSTRUCTED WITHIN THE LIMITS OF THE RIGHT OF WAY AND THE CURVE IS LONGER THAN THE SIGHT DISTANCE REQUIRED

Road center-line radius, in feet	200′ sight distance	300′ sight distance	400′ sight distance	500′ sight distanc[e]
	Values given below are the distance from the road center line to the right of way on the inside of the curve to give the sight distance shown at the head of each column.			
100	100.0			
150	38.0	150.0		
200	26.8	64.3	200.0	
250	20.8	50.0	100.0	250.0
300	17.1	40.2	76.3	134.0
400	12.7	29.2	53.6	87.6
500	10.1	23.0	41.8	67.0

TABLE 42.—TABLE OF RADII OF CENTER LINE REQUIRED FOR DI[F]FERENT SIGHT DISTANCES AND DIFFERENT RIGHT-OF-WAY WIDTHS, ASSUMING THAT THE LINE OF SIGHT IS TANGENT TO THE RIGHT OF WAY LINE

This permits building being erected on the line. This tab[le] indicates minimum curvature for certain limiting right-of-wa[y] widths, metropolitan districts.

Total width of right of way in feet, center line of road located in center of right of way	200′ sight distance	300′ sight distance	400′ sight distance	500′ sight distance
	Values given below are the approximate radii in feet of the road center line to give the required sight distance.			
50	212	463	812	1262
60	182	390	682	1056
80	145	301	520	801
100	125	250	425	650

Modifications for clearing depend on the height and thickness [of] the growth. The object of clearing is, first, to remove growt[h] within the slope lines; second, to provide a clear view; and, third, [to] clear sufficient width to allow the sun to reach the road, dry it ou[t] and melt snow. This last depends a good deal on the direction i[n] which the road is running, the altitude, and geographical locatio[n]. It is entirely a matter of judgment, but should be liberal in the fo[r]est districts and ranges from 30′ in low growth to 150′ in advers[e] locations and high growth. In high altitudes roads are at their bes[t] closed in winter, and if careful location and liberal clearing wi[...]

rease the length of the open season it is well worth while, as, in ect, it increases the usefulness of the road by 15 to 25%.

Recommended Practice.—All the evidence seems to indicate t the following normal right-of-way widths will be satisfactory, ovided they are modified for unusual conditions of grading, sight tance, and clearing.

TABLE 43

	Main routes, in feet	Secondary roads, in feet	Local roads, in feet
ountainous regions (cheap land)	150	100	100
rming country (moderately cheap land)	100	70	50
etropolitan districts (expensive land)	80	60	50

CHAPTER IV

DRAINAGE

CULVERTS, BRIDGES, DITCHES, UNDERDRAINS, AI STORM SEWERS

The problem of drainage may be divided into three parts:

1. Cross-drainage (pp. 180 to 333).
2. Longitudinal surface drainage (pp. 334 to 338).
3. Underdrainage (pp. 338 to 341).

Adequate drainage is essential to the success of road constructi As this element of design and construction is a fundamental pern nent requirement, it is entitled to reasonable liberality in expen ture and to reasonable allowances for future flow and tra conditions. Liberal waterway, safe roadway widths, and adequ strength of structures must be provided. Reasonable economy drainage design is confined to the selection of the most economi type of structure which will serve present and possible future c ditions. The selection of economic type depends on the topograp of the stream crossing, height of banks, foundation conditio length of span, proper use of piers, the necessity of future widen of the superstructure, the relative local costs of concrete or st masonry and steel and the utilization of old structures eit in whole or in part. Utilization of old structures very materia reduces bridge costs as discussed on pages 210 and 1013. A typi preliminary investigation report is given on page 327, supplement by quick-estimating diagrams to illustrate economic selection culverts and bridges. It is essential that each structure recei careful economic engineering design analysis. Stereotyped use standards is to be avoided. A sliding-scale standardization small culverts and bridge superstructures is convenient and app cable to most cases. *Bridge foundation design, however, cannot economically standardized.*

CROSS-DRAINAGE

Cross-drainage includes culverts and bridges located at natu stream crossings, natural swales, artificial drainage or irrigati ditches, low points on the road profile, equalizing culverts whe the road passes through a naturally depressed sump area, overflo culverts in flooded areas, and ditch relief culverts on long grade

If the funds are limited, the cheaper types may be used, but a necessary structures must be built not only to protect the road bu to establish a reasonable drainage scheme which is recognized ar becomes fixed by usage as the country develops; it is very difficu

ɔ change surface drainage in well-settled districts without annoying nd expensive lawsuits.

This chapter gives a short discussion of the essential elements of esign, illustrated by standard current practice for culverts and nall-span bridges. Long-span bridges are a specialized subject nd the reader is referred to standard bridge books for data on their esign and construction. Graphs (pp. 310 to 325) give sufficient ata for preliminary estimates of cost and the selection of economic ype for such bridges. The points to be considered in culvert and ridge design are:

a. Location of structure and channel improvements.
b. Waterway area and clearance for ice and débris.
c. Slope and elevation of culvert inverts.
d. Dead and live loadings.
e. Roadway widths and clearances.
f. Type of structures.
g. Protection from scour.

Location of Structure.—Poor location of structure is the most revalent fault of the usual road drainage scheme. A good location ılfils the fundamental requirement of getting water across and way from the road as soon as possible. It also considers the esirability of a fairly uniform velocity of flow of the water in the hannel and through the structure in order to minimize scour or ilting up of the waterway. Sharp changes of direction in the flow f water are undesirable, as they check velocity and produce ice or lébris jams as well as tend to clog the channel with silt deposits. Comparatively inexpensive channel straightenings often materially educe the spans and cost of bridges. *The necessity for careful tudies of location and channel improvements is emphasized.*

Simple Illustrations of Culvert Locations. *Case I. Simple Right-angle Stream Crossing* (Fig. 43).—There is never any doubt in

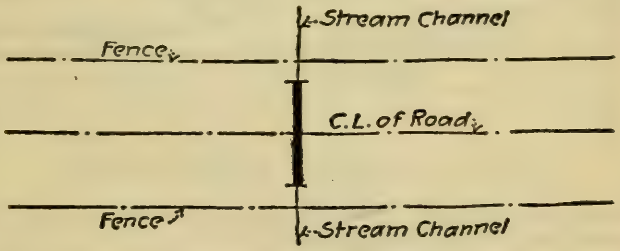


FIG. 43.—Case I. Culvert location.

his case. The structure is placed directly in the stream line and ıt right angles to the road center line.

Case II. Stream Crossing on Skew Angle (Fig. 44).—In a case of his kind it is desirable to place the culvert in line with the natural tream channel.

The right-angle location marked "poor" saves length of culvert, out generally requires four sharp changes in direction of flow which end to check the velocity of flow and to produce scour and silting

up at the angles. Considering maintenance cost, this type i generally poor economy unless the creek channel can be change for some distance.

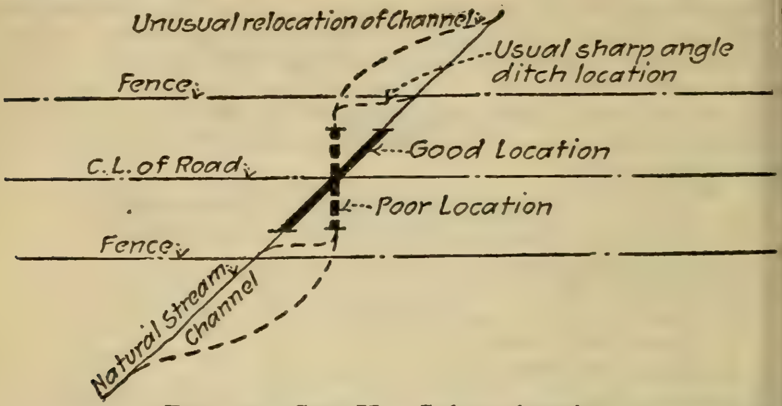


FIG. 44. Case II. Culvert location.

Case III. Where Stream Must Be Carried Along Road for Som Distance (Fig. 45).—The location marked "good" gets the water o to the low side of the road as soon as possible, minimizes shar changes in the direction of flow, and is desirable unless houses o barns are located on the low side of the road between the points a which the stream strikes and leaves the road.

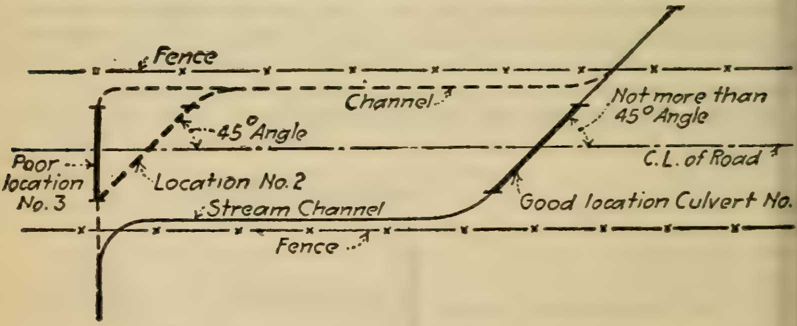


FIG. 45.—Case III. Culvert location.

Location 2 is desirable where houses are located on the low side of the road but not at the high side.

Location 3 is not desirable under any condition, as it checks flow and causes trouble by reducing the culvert capacity and encouraging scour and silting. In a number of cases locations of this nature have proved very unsatisfactory.

Case IV. Ditch Relief Culverts on Side-hill Location (Fig. 46).—Ditch relief culverts on side-hill locations are very desirable, as they minimize ditch scour. They are placed at any natural gully formation and on uniform slope formations are spaced from 300 to 500′.

The spacing between these ditch relief culverts on hill-side locations depends on the grade, soil, ditch lining, and width of

ction. A narrow 10′ mountain road requires more relief than a ′ road in the same location, as even a small washout will put the rrower road out of commission, while a moderately bad ditch our will not stop traffic in the second case. No set rules on spacing n be given, but current practice favors ditch relief culverts on

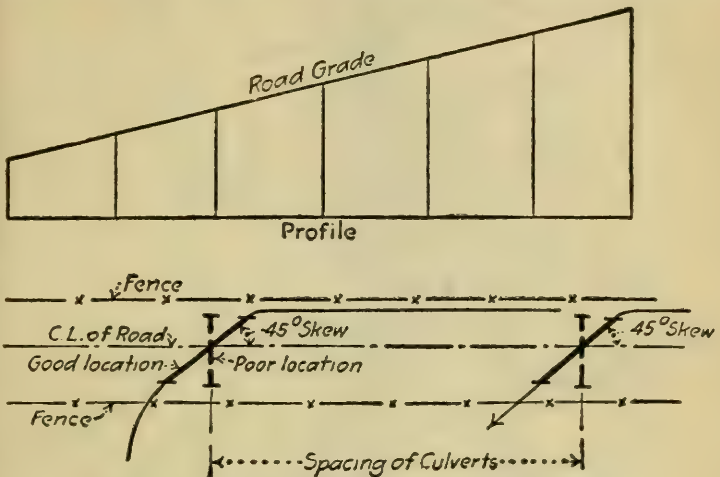


FIG. 46.—Case IV. Ditch relief culverts.

% grades at intervals not exceeding 300′, and on 5% grades not xceeding 500′. If cobble gutter or concrete ditch lining is used, e distance can be materially increased but is not advised. On ng cut and fill hills, drop inlets into storm sewers are sometimes ecessary to prevent overloading of the ditch.

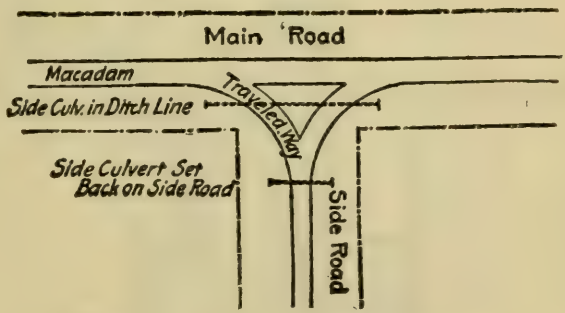


FIG. 47.—Case V. Side culverts.

Case V. Side Culverts (Fig. 47).—In designing culverts under de roads, the length must be great enough to provide an easy turn or traffic; many times a saving in length can be made by placing e culvert a short distance down the side road, as shown in Fig. 7, but this should, of course, not be done on steep grades.

Case VI. Bridge and Channel Locations (Figs. 48 and 49).—igures 48 and 49 illustrate road approach relocation and simple

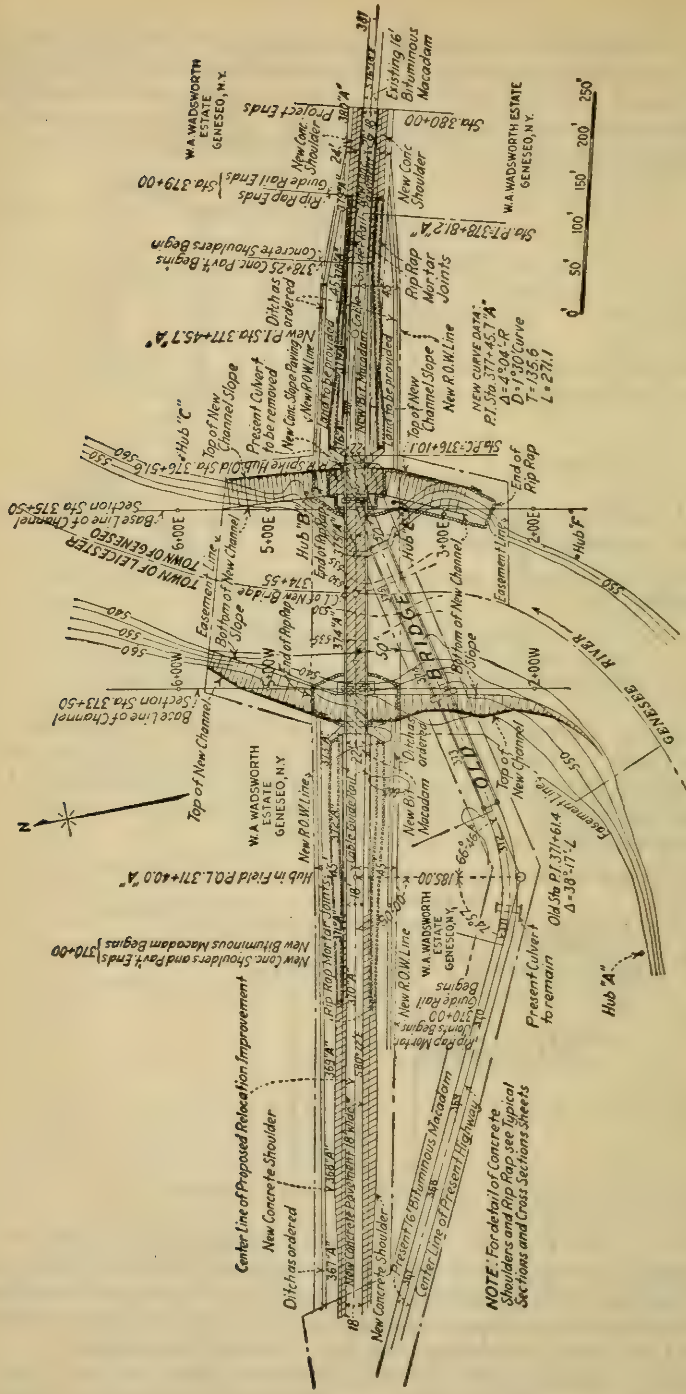


FIG. 48.—General layout bridge No. 5 road 1247. Showin improved road approach alignment, short right angle span an channel improvement.

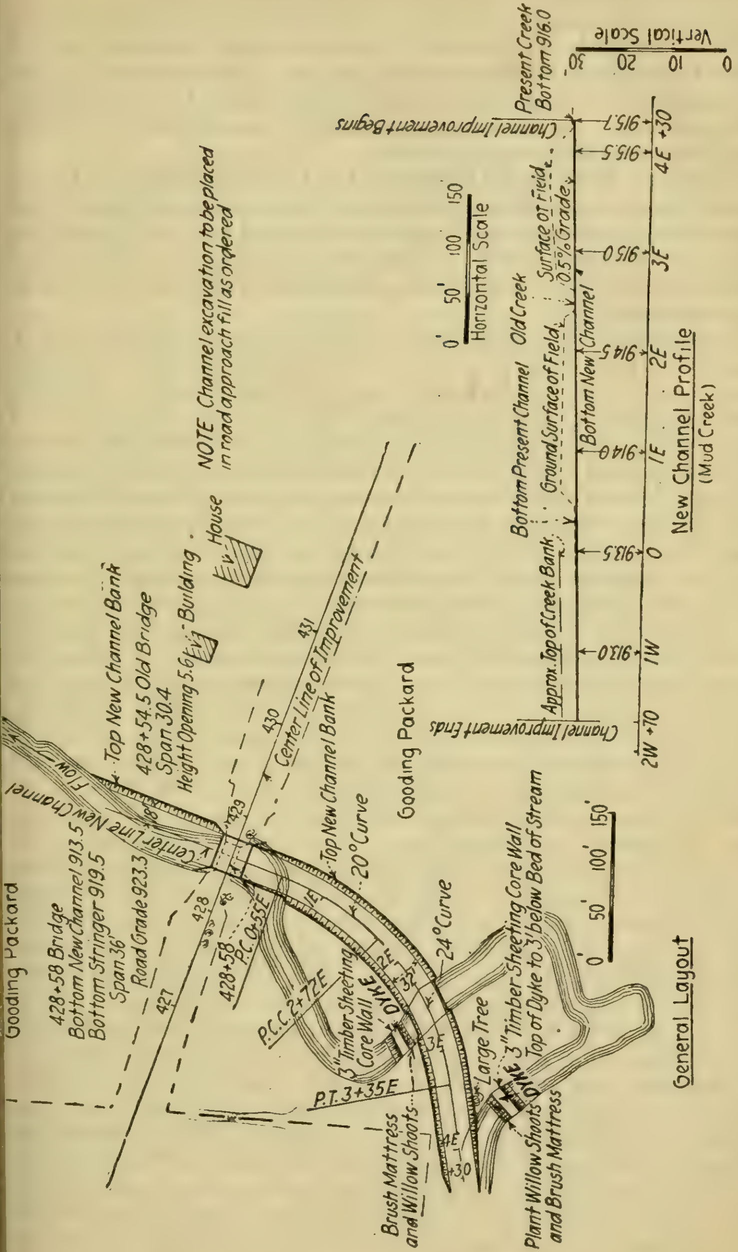


FIG. 49.—Channel improvement reducing required span and minimizing scour and silting at bridge site.

inexpensive channel improvement which betters road approache betters flow conditions, and reduces cost of structure.

Don'ts.—The main fault to be avoided in the location design culverts and bridges is the use of the right-angle location where th is not the natural and reasonable layout. The right-angle layo is desirable on account of economy, where it fits the conditions.

Do not omit culverts on side-hill locations and run the water f long distances in the road ditches.

Waterway Area and Clearance for Ice and Débris.—The si of opening and elevation of bottom of superstructure (top of ope ing), depend on volume and velocity of stream flow and on clearan for ice and floating débris. They should generally conform to t natural conditions at the stream crossing and permit a normal flo at normal velocity.

Clearance for Ice and Débris.—For culverts and small-span co crete structures (less than 10′) no allowance is made for déb clearance, as it rarely does any damage to the structure, and sho small pondings during exceptional flow can be disregarded. (larger streams requiring spans of over 10′, a minimum clearan between bottom of structure and high-water surface is general specified. Iowa specifies a minimum clearance of 1.0′ for spans 12 to 40′ and 2′ for spans longer than 40′. Maine specifies a mi mum of 4.0′ clearance for steel-girder or truss bridges. See pa 1025 for Western New York débris clearance practice. A reaso able underclearance is a local matter and no broad rule can be give

Volume and Flow of Water.—The size of opening is usua determined by noting the size of the old structure or, if none exis the size of other structures over the same stream and by inquiries neighboring residents or the road commissioner as to how the exi ing structure has handled the water in the past. As a general ru the size of opening or span should not be reduced below that of t present structure, but in steel bridges that have been sold town boards by enterprising bridge companies, it is often fou that the span is needlessly long. The evidence of existing str tures is the most reliable basis of design, but the conclusions sho be checked theoretically, and for small drainage areas in villa and all drainage areas affecting new locations in sparsely settl districts either the physical evidence of high water or some ma mum run-off formula must be used. Run-off formulas are based the rate of rainfall, area of the watershed, topography, and so The rate of rainfall varies for different geographical locations a the length of the storm. Reliable information for any locality c be obtained from the Weather Bureau. Short storms develop t greatest intensity and produce the largest run-off for small wat sheds. The rates reached by these storms should be considered designing ditch relief culverts or cross-culverts with small draina areas. A liberal basis for these cases is the 5- or 10-min. durati rate of Table 45 (p. 187). Table 46 (p. 188) illustrates the meth Most culvert design is based on a 24-hr. precipitation, as illustrat in Table 47 (p. 189), and applies to watersheds of, say, 0.5 sq. mi and up. Streams requiring structures of over 10′ span genera produce physical evidence of high water which can be safely use

Table 50 (p. 192) gives the size of opening used by the Santa Fé R.R.; Table 48 (p. 190) gives the size of opening for small culverts sed by the New York Central. Table 49 (p. 191) gives the size f culvert used by the Iowa State Highway Commission. These ables serve to illustrate the application of this principle of design.
Weather Bureau records show maximum 24-hr. precipitations of .66″ at Portland, Ore.; 5.12″ at Los Angeles, Cal., 2.06″ at El Paso, 'ex.; 7.03″ at Kansas City, Mo.; 9.40″ at New York City; and .57″ at Savannah, Ga. These rates are rarely used for run-off omputations as they represent extreme cases of rare occurrence. ;ood practice uses a 24-hr. rate of from 4 to 6″. Openings based on iese rates where the culvert will handle the water without quite ınning full will take care of unusual cases by the forced discharge ue to the formation of a shallow pond on the upstream side of the ɔad. Discharge velocity due to backwater head is shown approxiıately by Table 53 (p. 196).

TABLE NO. 45.—RATES OF RAINFALL. SHORT STORMS

Short storms of the greatest intensity occur as cloud-bursts n the mountain and arid regions between the Sierras and the foothills of the Rockies. The intensities of these storms are not well recorded but partial records indicate as high a fall as 11 nches in one hour. For these regions culverts for small drainage ıreas should be made at least twice as large as for eastern or southern conditions. (See last column, table No. 46.)

Maximum intensity of Rainfall for different periods taken from the U. S. Weather Bureau Records. Intensity at rate of inches per hour.

Location	5 Minute Duration	10 Minute Duration	One Hour Duration
Atlanta, Georgia	5.5 in.	5.5 in.	1.5 in.
Boston, Mass	6.7 in.	5.0 in.	1.7 in.
Chicago, Ill	6.6 in.	5.9 in.	1.6 in.
Cleveland, Ohio	5.6 in.	3.7 in.	1.1 in.
Denver, Colo	3.6 in.	3.3 in.	1.2 in.
Detroit, Mich	7.2 in.	6.0 in.	2.2 in.
Duluth, Minn	3.6 in.	2.4 in.	1.4 in.
Galveston, Tex	6.5 in.	5.6 in.	2.6 in.
Jacksonville, Fla	7.4 in.	7.1 in.	2.2 in.
Milwaukee, Wis	7.8 in.	4.2 in.	1.3 in.
Memphis, Tenn	6.6 in.	4.8 in.	1.9 in.
New Orleans, La	8.2 in.	4.9 in.	2.2 in.
Norfolk, Va	5.8 in.	5.5 in.	1.6 in.
Omaha, Neb	6.0 in.	4.8 in.	1.6 in.
Philadelphia, Penn	5.4 in.	4.0 in.	1.5 in.
Savanah, Geo	6.6 in.	6.0 in.	2.2 in.
St. Louis, Mo	4.8 in.	3.8 in.	2.3 in.
Washington, D. C	7.5 in.	5.1 in.	1.8 in.

TABLE 46.—MAXIMUM RUNOFF. SMALL WATERSHEDS BURKLI ZIEGLER, SEWER FORMULA

$$\text{Cubic feet per second per acre reaching culvert.} = C \times \left\{ \begin{array}{l} \text{Av. cu. ft. rainfall} \\ \text{per second per acre} \\ \text{during heaviest fall.} \end{array} \right\} \times \sqrt[4]{\frac{\text{Av. slope of ground in feet per 1000}}{\text{No. of acres drained}}}$$

C = 0.75 for paved streets and built up business blocks.
C = 0.625 for ordinary city streets.
C = 0.30 for villages with lawns and macadam streets.
Assumed C = 0.25 for farming country. NOTE.—This value is high from the standpoint of sewer design but culverts are short and might better be liberal in size.

One inch of rainfall per hour equals 1 cu. ft. per second per acre.

DISCHARGE IN CUBIC FEET PER SECOND

Area in Acres	Rate of Rainfall 4″ per Hour						**Assumed Runoff Steep Stony Mountain Slopes
	Fall 5′ in 1000		Fall 20′ in 1000		Fall 50′ in 1000		
	C=0.30	C=0.25	C=0.30	C=0.25	C=0.30	C=0.25	Rainfall 8″ per Hour
1	1.8	1.5	2.5	2.1	3.1	2.7	6
2	3.0	2.5	4.2	3.5	5.4	4.5	12
3	4.1	3.4	5.7	4.8	7.2	6.0	18
4	5.0	4.2	7.2	6.0	9.0	7.5	23
5	6.0	5.0	8.5	7.1	10.7	8.9	23
6	6.8	5.7	9.7	8.1	12.2	10.2	33
7	7.7	6.4	10.9	9.1	13.7	11.4	38
8	8.5	7.1	12.0	10.0	15.1	12.6	42
9	9.3	7.8	13.2	11.0	16.5	13.8	46
10	10.1	8.4	14.3	11.9	18.0	15.0	50
20	16.9	14.1	24.0	20.0	30.2	25.2	90
30	23.0	19.2	32.5	27.1	40.7	33.9	120
40	28.5	23.8	40.3	33.6	50.9	42.4	150
50	33.6	28.0	47.7	39.8	60.0	50.0	180
60	38.6	32.2	54.6	45.5	68.7	57.3	200
70	43.3	36.1	61.4	51.2	77.3	64.4	225
80	48.0	40.0	67.9	56.6	85.2	71.0	250
90	52.4	43.7	73.9	61.6	93.1	77.6	275
100	56.7	47.3	80.2	66.8	100.8	84.0	300
200	95.4	79.5	134.6	112.2	169.7	141.4	550
300	129.0	107.7	182.9	152.4	229.7	191.4	750
400	160.0	133.6	227.0	189.2	285.6	238.0	880
500	190.0	158.0	268.0	223.5	336.6	280.5	980
600	216.0	180.0	307.0	256.0	387.0	322.8	1,050
640	230.0	*192.0	323.0	269.0	406.3	338.6	1,100

* 200 second feet by Table 47.
** Based on Santa Fe Table 50.

TABLE 47.—MAXIMUM RUNOFF, DICKENS FORMULA

$D = C\sqrt[4]{M^3}$ Runoff expressed in second feet. D = Discharge in cu. ft. second. M = Drainage area in sq. miles. C = Coefficient.

The following tabulation is for a 24 hour precipitation of 4″ in and for topography similar to the farming sections of the astern Atlantic States. For 6″ in 24 hours correct the quantities in proportion to C as follows.

4″ Rainfall		6″ Rainfall	
Flat Country	C = 200	Flat Country	C = 300
Rolling Country	C = 250	Rolling Country	C = 325
Hilly Country	C = 300	Hilly Country	C = 350

For steep stony watersheds and a 6″ rainfall use the Oklahoma Column of Table 50.

Area in Square Miles	Flat Country C 200	Rolling Country C 250	Hilly Country C 300
0.1 = 64 acres	36	45	54
0.2	60	75	90
0.3	81	101	121
0.4	100	125	150
0.5	119	149	180
0.6	136	170	204
0.7	153	191	229
0.8	169	211	253
0.9	185	231	277
1.0	200	250	300
2.0	334	417	501
3.0	456	570	684
4.0	564	705	846
5.0	668	835	1002
6.0	764	955	1146
7.0	860	1075	1290
8.0	950	1188	1426
9.0	1038	1297	1556
10.0	1122	1402	1682
20.0	1890	2362	2834
30.0	2560	3200	3840
40.0	3180	3975	4770
50.0	3760	4700	5640
60.0	4310	5400	6480
70.0	4840	6050	7260
80.0	5360	6700	8040
90.0	5840	7300	8760
100.0	6320	7900	9480

or areas under 0.1 square mile, see Table 46

OTE.—For graph of this table see page 1021.

Examples of Use of Tables.—Table 51 (p. 194) gives the norm discharge of small culverts laid at different rates of grade. ' illustrate the use of Tables 45 to 51, three examples will be give Suppose water from 2 sq. miles of flat farming country in the Nor Atlantic states is to pass through a culvert having a natural slo of 0.5′ per 100′. Table 47 is figured for a 4″ rainfall in 24-hr., whi is reasonable for this section. This table shows a run-off of 3 sec.-ft. for flat farm land. For a slope of 0.5′ per 100′, Table shows that a 5 by 5′ culvert will carry the water.

Suppose steep, rocky ground is to be considered of, say, 200 ac or ⅓ sq. miles in Oklahoma and a culvert slope of 2′ per 100′. T best data are the Santa Fé (Table 50), which give an opening of sq. ft. at 10′ per second or a run-off of 510 sec.-ft. Table 51 sho that a 5 by 4′ culvert on a 2% grade will carry this, but that t velocity is high and the culvert must have a solid bottom and r rap protection at both ends. Where pipes or solid bottom culve are used, high velocity is not objectionable, but where the bric type is used a sufficiently large opening to keep the velocity do to 10′ per second or less is advisable.

Suppose a ditch relief culvert drains 2 acres in the cloud-bu region and can be laid on a slope of 3′ per 100′. Use last colu (Table 46), which gives 12 sec.-ft., which, from Table 51, give 16″ pipe.

Table 52 gives the approximate velocity of flow in ditches a streams knowing the cross-section area and slope of water surfa

Table 53 gives the approximate increase in elevation abov bridge in a stagnant-flow area to force water through the bri opening at different velocities.

See also typical bridge reports (pp. 327 to 333) for determinat of waterway area and débris clearance allowance.

TABLE 48.—NEW YORK CENTRAL & HUDSON RIVER R.R. CULVE FOR SMALL DRAINAGE AREAS

Steep, rocky ground, acres	Flat cultivation, long valley, acres	Size, diameter in inches	Equivalent capa ity, pipes
5	10	10	
10	20	12	
20	40	16	
25	50	18	Two 16″ pipes
30	60	20	Two 16″ pipes
45	90	24	Two 18″ pipes
70	140	30	Two 24″ pipes
110	220	36	Two 30″ pipes
150	300	42	Two 30″ pipes
180	360	48	Two 36″ pipes
280	560	60	Two 36″ pipes

NOTE.—To be used only in the absence of more reliable information, par ularly on existing culverts over the same stream.

BLE 49.—CULVERT DESIGN, IOWA STATE HIGHWAY COMMISSION

Size of culvert opening, feet	Maximum acres	Minimum acres
2 by 2	70	28
4 by 4	376	140
6 by 6	1300	520
8 by 8	2700	1120
10 by 10	5000	2000

Iowa State Design Specifications, 1925 (Waterway Area)

. **Determination of Size of Opening.**—In general, the determination of size of the waterway opening required shall be made by the engineer m a study of the topographic and local conditions, available previous ords of stream run-off, high-water, and other available data. The uired field data for the determination of waterway opening are given in ail in a field manual entitled "Instructions for Making Bridge and Cul-t Surveys." The general methods of determination of waterway open-s shall be as follows:

. *Small Structures.*—For small structures having waterway openings not ater th n 400 sq. ft. the area of opening required may be determined by lbot's formula, $A = C\sqrt[4]{D^3}$,

ere A = area of waterway opening, in square feet.
C = coefficient:

Mountainous	= 1.0
Hilly	= 0.6 to 0.8
Rolling	= 0.4 to 0.5
Flat	= 0.2 to 0.3

D = drainage area, in acres.

. *Medium-sized Structures.*—The size of opening required for medium-d structures having areas of openings from 400 to 1000 sq. ft. shall be ermined by the engineer from a study of the available data on topo-phic conditions, stream run-off, high water, and by a comparison of the ues obtained from such studies with those obtained from other data, h as Talbot's formula, Dunn's table, etc. The use of an empirical mula alone in determining the size of opening required for structures of s size is not recommended.

. *Large Structures.*—The waterway opening for structures having required nings greater than 1000 sq. ft. shall be determined by the engineer from a dy of topographic conditions in the vicinity of the proposed structure, t records of high water and run-off, and the determination of probable am run-off, using available data on the stream slope, mean velocity, and ss-sectional area of the stream below high water. A comparison should made of the values thus obtained with the actual area of openings of sting structures on the same stream or on other streams under similar ditions. Empirical formulas having as factors only drainage areas and fficients are not applicable in determining the size of openings for struc-es of this size.

TABLE 50.—SANTA FÉ RY. SIZE OF OPENING

Area Drained in Square Miles	Areas of Waterways Sq. Ft.			Area Drained in Square Miles	Areas of Waterways Sq. Ft.			Area Drained in Square Miles	Areas of Waterways Sq. Ft.			Area Drained in Square Miles	Areas of Waterways Sq. Ft.		
	Missouri and Kansas A	Okla-homa	Illinois		Missouri and Kansas A	Okla-homa	Illinois		Missouri and Kansas A	Okla-homa	Illinois		Missouri and Kansas A	Okla-homa	Illinois
0.01	2.0	2.0	East of Streator use 60% of Column A West of Streator use 80% of Column A	0.85	91.0	91.0	East of Streator use 60% of Column A West of Streator use 80% of Column A	4.2	403	409	East of Streator use 60% of Column A West of Streator use 80% of Column A	20	970	1062	East of Streator use 60% of Column A West of Streator use 80% of Column A
0.02	4.0	4.0		0.90	94.0	94.0		4.4	417	423		22	1015	1120	
0.03	6.0	6.0		0.95	97.0	97.0		4.6	430	436		24	1060	1170	
0.04	7.5	7.5		1.0	100.0	100.0		4.8	443	450		26	1100	1220	
0.05	9.0	9.0		1.1	110.0	111.0		5.0	455	464		28	1140	1275	
0.06	10.5	10.5		1.2	120.0	121.0		5.5	483	493		30	1180	1320	
0.07	12.0	12.0		1.3	130.0	131.0		6.0	509	519		32	1220	1370	
0.08	13.5	13.5		1.4	140.0	141.0		6.5	533	545		34	1255	1415	
0.09	15.0	15.0		1.5	150.0	151.0		7.0	556	572		36	1290	1460	
0.10	16.0	16.0		1.6	160.0	162.0		7.5	579	596		38	1320	1505	
0.15	25.0	25.0		1.7	170.0	172.0		8.0	601	622		40	1350	1575	
0.20	32.0	32.0		1.8	180.0	182.0		8.5	622	644		45	1435	1645	
0.25	38.0	38.0		1.9	190.0	192.0		9.0	641	666		50	1510	1745	
0.30	44.0	44.0		2.0	200.0	202.0		9.5	660	689		55	1580	1840	
0.35	51.0	51.0		2.2	220.0	223.0		10.0	671	709		60	1650	1930	
0.40	56.0	56.0		2.4	240.0	244.0		11.0	710	745		65	1720	2020	
0.45	62.0	62.0		2.6	260.0	264.0		12.0	740	781		70	1780	2100	
0.50	66.0	66.0		2.8	280.0	284.0		13.0	775	815		75	1840	2180	
0.55	70.0	70.0		3.0	300.0	304.0		14.0	805	857		80	1900	2255	
0.60	74.0	74.0		3.2	321.0	326.0		15.0	835	893		85	1980	2330	
0.65	78.0	78.0		3.4	340.0	345.0		16.0	865	930		90	2015	2405	
0.70	81.0	81.0		3.6	357.0	362.0		17.0	890	951		95	2065	2475	
0.75	85.0	85.0		3.8	373.0	379.0		18.0	920	998		100	2120	2545	
0.80	88.0	88.0		4.0	388.0	394.0		19.0	945	1020		110	2220	2690	

120	2315	2820	East of Streator use 60 % of Column A West of Streator use 80 % of Column A	300	3615	4690	East of Streator use 60 % of Column A West of Streator use 80 % of Column A	850	5940	7640	East of Streator use 60 % of Column A West of Streator use 80 % of Column A	2000	8820	11450	East of Streator use 60 % of Column A West of Streator use 80 % of Column A
130	2405	2955		325	3770	4860		900	6080	7875		2200	9240	11960	
140	2500	3080		350	3900	5040		950	6230	8170		2400	9605	12490	
150	2580	3240		375	4035	5220		1000	6380	8410		2600	9970	12995	
160	2665	3330		400	4165	5400		1100	6705	8720		2800	10370	13680	
170	2745	3445		450	4385	5660		1200	6960	9030		3000	10640	14370	
180	2820	3560		500	4610	5920		1300	7230	9340		3500	11445	15050	
190	2900	3665		550	4825	6175		1400	7480	9650		4000	12160	15740	
200	2970	3775		600	5030	6440		1500	7725	9960		4500	12825	16475	
220	3115	3980		650	5230	6695		1600	7960	10270		5000	13500	17275	
240	3245	4152		700	5420	6335		1700	8195	10580		5500	14080	18125	
260	3370	4330		750	5610	7170		1800	8390	10890		6000	14520	18975	
280	3495	4510		800	5800	7400		1900	8625	11200		6500	15140	19825	

NOTE.—The above classification by states is for convenience only, and merely denotes the general characteristics of topography and rainfall. Column A in table is prepared from observations of streams in southwest Missouri, eastern Kansas, western Arkansas and the southeastern portion of the Indian Territory. In all of this region, steep rocky slopes prevail and the soil absorbs but a small percentage of the rainfalls, and indicates larger waterways than are required in western Kansas and the level portions of Missouri, Colorado and New Mexico or Western Texas. This table is based on data procured from different western railroads, and from actual surveys and on a 6″ rainfall in 24 hours taken from Government statistics, with the understanding that most of it falls in 6 or 8 hours, and velocity under bridge or through opening is 10′ per second. From the above it is obvious that each waterway should be given a certain amount of individual consideration, and if it is desirable to depart from waterways in table, full explanation of conditions and reason for departure should be given.

Approved:

R. A. RUTLEDGE,
Chief Engineer.

See Vol. XI, No. 2, April, 1906, Journal Western Soc. of Engrs. for report on Dun's waterway table.
C. E. O., April 13, 1914.

TABLE 51.—APPROXIMATE DISCHARGE CAPACITY CAST-IRON PIPE AND SMALL CONCRETE BOX CULVERTS

Velocity in Feet per Second — Discharge in Cu. Ft. per Second

Slope in Feet per 100	12″ C. I. P.		14″ C. I. P.		16″ C. I. P.		18″ C. I. P.		20″ C. I. P.		22″ C. I. P.		24″ C. I. P.	
	Vel.	Dis.	Vel.	Dis.	Vel.	Dis.	Vel.	Dis.	Vel.	Dis.	Vel.	Dis.	Vel.	Dis.
0.5					4.5	6	5.0	9	5.4	12	5.8	15	6.2	19
1.0					6.8	9	7.0	12	7.7	17	8.2	22	9.2	29
2.0	7.4	6	8.3	9	9.2	13	10.0	13	10.9	24	11.5	30	12.3	39
3.0	9.2	7	10.3	11	11.2	16	12.2	21	13.4	29	14.2	37	14.8	46
4.0	10.6	8	11.8	12	13.1	18	14.2	25	15.3	34	16.5	43	17.2	54
5.0	11.8	9	13.3	14	14.6	20	16.2	28	17.3	33	18.0	48	19.0	60
6.0	13.0	10	14.6	15	16.2	23	17.5	31	19.0	41	20.0	53	21.3	67
Area Sq. Ft.	0.78		1.07		1.39		1.76		2.17		2.64		3.14	
Value of R	0.25		0.29		0.33		0.37		0.42		0.46		0.50	

CONCRETE BOXES

Slope in Feet per 100	2′ × 1.5′		2′ × 2′		3′ × 2′		3′ × 3′		4′ × 2′		4′ × 3′		4′ × 4′		5′ × 3′		5′ × 4′		5′ × 5′	
	Vel.	Dis.	Vel.	Dis.	Vel.	Dis.	Vel.	Dis.	Vel.	Dis.	Vel.	Dis.	Vel.	Dis.	Vel.	Dis.	Vel.	Dis.	Vel.	Dis.
0.5	7.0	21	7.7	31	8.6	52	9.7	87	9.7	78	10.8	130	11.6	186	11.9	179	13.0	260	13.8	340
1.0	10.0	30	10.4	42	12.5	75	13.7	123	13.7	110	15.0	180	16.7	267	16.9	254	18.5	370	19.0	475
2.0	14.0	42	14.8	59	17.5	105	19.0	171	19.0	152	22.0	264	23.6	378	23.8	357	26.2	523	28.0	700
3.0	17.2	52	18.3	73	21.6	130	23.5	212	23.5	188	26.5	318	29.0	464	29.5	443				
4.0	20.0	60	21.0	84	24.8	149	27.5	248	27.0	216	30.5	366								
5.0	22.6	68	23.5	94	27.5	165	31.0	279	31.0	248										
6.0	24.0	72	26.0	104	30.0	180														
Area Sq. Ft.	3.0		4.0		6.0		9.0		8.0		12.0		16.0		15.0		20.0		25.0	
Value of R	0.60		0.66		0.86		1.0		1.0		1.2		1.33		1.36		1.54		1.66	

Note:—Table 51 is figured from Church's diagrams of Kutters formula using n = 0.011; the use of these diagrams for short culverts is approximate only but it is sufficiently close for the purposes for which this table is intended.

TABLE 52.—APPROXIMATE MEAN VELOCITIES OF FLOW

(In feet per second)

Coefficient of friction N = 0.03 channel in fair condition.

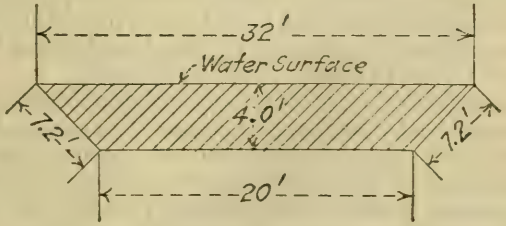
$$R = \text{hydraulic radius} = \frac{\text{Water flow area (square feet)}}{\text{Wetted perimeter of channel (Linear feet)}}.$$

(*Compiled from Church's diagrams of Kutter's formula*)

lope of hannel in feet er 1000′	Hydralic radius R										
	0.2	0.4	0.6	1	2	3	4	6	8	10	20
0.01	....	....	....	.....	0.22	0.32	0.42	0.6	0.8	0.92	1.7
0.1	....	0.18	0.28	0.42	0.75	1.0	1.3	1.7	2.2	2.4	4.0
0.2	0.16	0.28	0.42	0.61	1.08	1.45	1.75	2.4	2.9	3.4	5.4
0.3	0.19	0.36	0.51	0.77	1.3	1.75	2.2	2.9	3.5	4.1	6.4
0.4	0.22	0.42	0.59	0.9	1.5	2.05	2.45	3.4	4.0	4.7	7.3
0.5	0.26	0.48	0.66	1.0	1.7	2.25	2.8	3.75	4.5	5.3	8.2
1.0	0.37	0.68	0.94	1.4	2.4	3.2	3.95	5.2	6.3	7.3	11.5
2.0	0.52	0.96	1.35	2.0	3.4	4.6	5.6	7.3	9.1	10.4	16.5
3.0	0.64	1.2	1.7	2.5	4.2	5.6	6.9	9.0	11.0	13.0	19.5
4.0	0.74	1.3	1.85	2.8	4.8	6.4	7.9	10.2	12.8	14.5	22.5
5.0	0.83	1.5	2.15	3.2	5.4	7.2	8.9	11.6	14.0	16.5	25.5
6.0	0.91	1.7	2.3	3.5	5.9	7.9	9.8	12.8	15.8	17.7	27.5
7.0	0.98	1.8	2.5	3.8	6.4	8.6	10.5	13.6	17.0	19.0	29.5
8.0	1.04	1.9	2.7	4.1	6.9	9.2	11.2	14.5	18.0	20.5	32.0
9.0	1.10	2.05	2.8	4.3	7.3	9.7	11.9	15.5	19.0	22.0	34.0
10.0	1.19	2.2	3.0	4.5	7.7	10.2	12.6	16.5	20.0	26.0	36.0
15.0	1.4	2.7	3.7	5.5	9.5	13.0	15.5	20.0	25.0	28.0	
20.0	1.7	3.1	4.3	6.4	10.9	14.5	18.0	23.0	28.0	33.0	
30.0	2.1	3.8	5.2	7.9	14.5	18.0	22.0	28.0	35.0		
40.0	2.4	4.3	6.1	9.1	15.5	21.0	25.0	33.0			
50.0	2.7	4.8	6.8	10.1	17.5	23.0	28.0	37.0			
100.0	3.8	6.8	9.5	14.2	24.0	33.0	40.0				

NOTE.—For coefficient of friction of 0.035, channels in poor condition, e 85 % of the velocities given in the above table.

Example of Use of Table 52.—To find velocity of flow and carrying pacity of improved channel having a 20′ bottom width, 1 on $1\frac{1}{2}$ le slopes, and a 4′ depth of water. Channel on grade of 0.1 % ′ per 1000′).



$$\text{Flow area} = \frac{32 + 20}{2} \times 4 = 104 \text{ sq. ft.}$$

$$\text{Wetted perimeter} = 20 + 7.2 + 7.2 = 34.4'$$

$$\text{Hydraulic radius } R = \frac{104}{34.4} = 3.0.$$

Channel in fair condition $N = 0.03$

From table, mean velocity of flow for $N = 0.03$, $R = 3.0$, and fall of 1.0′ per 1000′ equals = 3.2′ per second.

Carrying capacity of channel = 104 sq. ft. × 3.2 = 332.8 cu. ft. per second.

For channel in poor condition use velocity for $N = 0.035$, which is 85% of 3.2 = 2.7, 104 × 2.7 = 281 cu. ft. per second.

TABLE 53.—APPROXIMATE BACKWATER HEAD IN FEET, TO GIVE DIFFERENT VELOCITIES OF FLOW THROUGH BRIDGE OPENING

$$H = \frac{V^2}{2g} = \frac{V^2}{64.4} \text{ or } V = \sqrt{64.4\,H}$$

Approximate backwater head, feet	Forced velocity, feet per second
0.1	2.5
0.2	3.6
0.3	4.4
0.4	5.1
0.5	5.7
0.6	6.2
0.7	6.7
0.8	7.2
0.9	7.6
1.0	8.1
1.5	9.8
2.0	11.4

Practical Considerations Governing the Size of Waterway.—For moderate-sized drainage areas the culvert opening is proportioned to the run-off, but for small areas the size is determined by the convenience of cleaning rather than by the discharge capacity. Where sufficient fall can be obtained to make the culvert self-cleaning, a 12″ pipe is feasible under shallow fills, but where the flow is sluggish, nothing less than a 16 to 18″ pipe will serve satisfactorily. Long culverts under deep fills should never be smaller than 2′ wide and 3′ high to permit cleaning by hand.

The self-cleaning velocity of flow for sand and earth particles is about 1′ per second; for coarse gravel, about 3′ per second (Ogden's "Sewer Design," p. 134). A pipe laid on a slope that gives a velocity of 5′ per second when flowing one-quarter full should keep clean. This requires a fall of approximately 2′ per 100′ for a 12″ pipe and is the minimum grade at which the 12″ size should be used as a short culvert. Long storm sewers use lighter grades (see Table 61, p. 338).

It is probable that a culvert should have the same slope as the stream bed. If given a greater slope, the outlet end tends to clog, and if a lesser, the inlet end will plug. It is unusual for culverts to

fill badly except when placed at the foot of a steep hillside where the stream velocity is materially reduced. At such points an extra large structure should be designed with the idea of providing sufficient waterway even after the contraction caused by this settlement has occurred. Such a culvert should be cleaned after each freshet. The use of short, paved dips in the roadway at such points in place of culverts is not advised, as they are dangerous and cause accidents unless very gradual. A man not familiar with the road often loses control of his car.

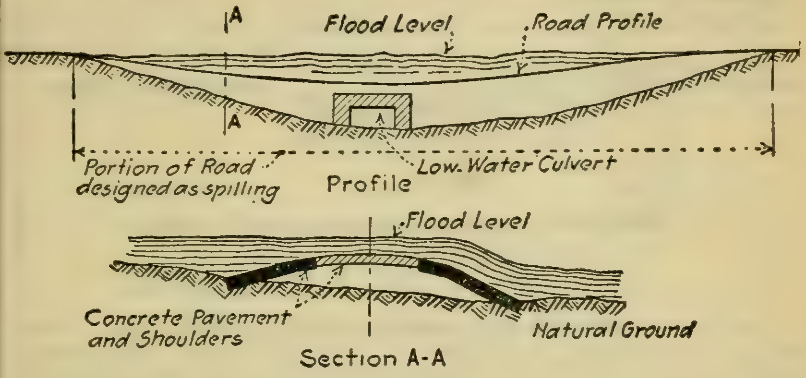


FIG. 50.—Overflow and low water culvert.

If, however, too much trouble is experienced in carrying large infrequent floods under the road, a small culvert can be used for the low-water flow which does not, as a rule, carry much silt, and the flood flow can be carried over the roadbed by paving the entire surface with concrete from toe of slope to toe of slope and giving the longitudinal road profile a slight dip safe for traffic to localize the flooded portion of the road (Fig. 50).

More trouble is experienced from culverts becoming filled with ice due to alternate freezing and thawing weather. This is particularly true of small culverts draining springs. Culverts as large as 2 by 2′ have frozen solid in this manner, and if this difficulty is anticipated the size should be regulated accordingly or trouble will be experienced during the spring break-up. The following ingenious expedient has been successfully used on roads where the culverts fill with ice and snow during the winter. A small pipe is suspended inside of the normal culvert. In the fall this small pipe is plugged, and in the spring just as the snow begins to melt the plugs are removed and the first water flowing through the small pipe melts the ice and snow rapidly for the entire length of the culvert so that it is generally completely free to handle the main spring run-off.

FIG. 51.—Small pipe in culvert.

Grade and Elevation of Culvert Inverts.—As previously stated, it is desirable to prevent silting up of the culvert due to abrupt

changes in the velocity of flow. For this reason culverts are normally given the same slope as the stream bed.

The elevation of the invert is always made low enough to drain all surface water from the upstream adjacent lands and, if the elevation of the outlet permits, it is desirable to make the culvert low enough to act as an outlet for farm underdrains. In hilly country, underdrainage need not be given much weight, but in flat country it often controls the elevation of the culvert invert.

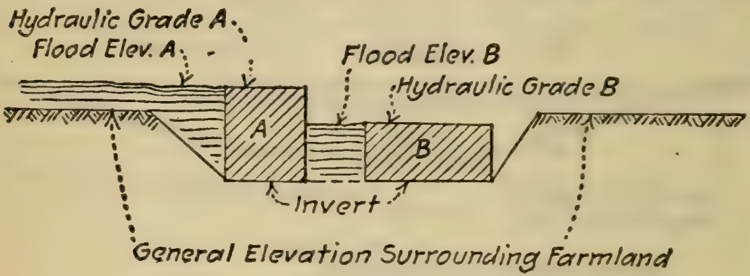


FIG. 52.

In order to prevent serious ponding and damage to crops in flat country, all culverts or bridges on channels of any importance should be placed at such an elevation that the top of the waterway opening is as low or lower than the surrounding farm land; that is, the culvert elevation and shape of opening should be designed for the hydraulic grade of maximum flood flow.

Figure 52 illustrates this point. The waterway areas of two culverts *A* and *B* are the same in size. In order to get the full capacity

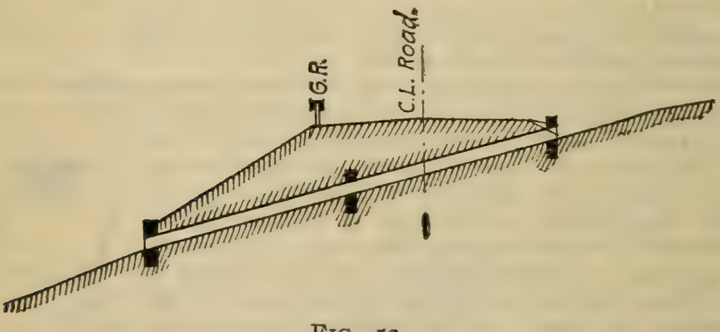


FIG. 53.

of *A*, however, the water would have to back up and overflow the surrounding lands. Culvert *B* carries the flood flow without serious ponding.

The use of bridge openings similar to *A* is very common practice in both railroad and highway design, as it generally cheapens the culvert, but is undesirable, causing needless damage to the abutting properties.

Where pipe culverts are laid on steep slopes, special buttresses,

well imbedded in the natural hard slope, should be provided to prevent crawl or slip. Well-built headwalls should hold up to, say, 12° side slope, and beyond this limit extra anchors should be provided (see Fig. 53).

Depth of Cushion under Pavement.—A cushion of earth between the top of a concrete culvert or pipe and the bottom of the pavement is desirable. This is more important where the pavement is a rigid type, such as brick or concrete, than where it is a macadam construction.

The depth of this cushion sometimes controls the culvert invert elevation where the topography and road grade make a low invert needlessly expensive or impracticable.

For rigid pavements the minimum desirable depth of cushion is approximately 6″. This cushion between culvert top and bot-

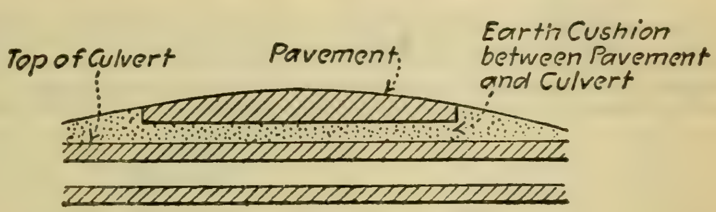


Fig. 54.—Cushion over culvert slabs.

tom of pavement should be gravel or macadam to prevent frost heave due to saturated earth. If less than this is used the chances are that the pavement will crack over the side walls of the culvert unless the pavement base is specially thickened and reinforced with steel. For macadam pavements, a 6″ cushion is desirable, but no great damage occurs if the bottom course is laid directly on the culvert top. Even with a cushion, settlement often develops each side of culverts having less than 2 to 3′ of cover, but it can be easily fixed by the maintenance gang.

Dead and Live Loads. *Dead Loads.*—Dead loads include weight of structure plus earth and pavement fills over the superstructure. They are readily determined. Weights of material making up dead loads are given in Table 172 (p. 1038). Dead-load computations should include future pavement surfacing to repair bridge floors. If the type of flooring used can be removed and replaced without additional thickness and weight, no extra allowance is required; if a solid concrete floor is used which in the future will be recapped with additional depth of asphaltic concrete or block pavement, the future extra weight must be considered.

Earth-fill loads on superstructures of culverts or bridges are usually computed for total depth between vertical planes at the ends of the structure and make no allowance for arch action of earth fills. Some designers reduce this load for arch action on the basis of inclined planes at an angle of about 20° with the vertical at the ends of the structure; but there have been enough cases of trouble with culverts under deep fills to warrant conservative assumptions in regard to vertical earth pressures, and the total earth weight between vertical planes seems justified as a basis of design.

Live Loads.—Live loads include weight of traffic plus impact allowance and are largely a matter of judgment. There is quite a range in the values used. It is universally conceded, however, that at least four classes of loading should be considered to meet variations, in local conditions prevailing in the United States and that it is neither wise nor economical to apply heavy-traffic loading to light-traffic bridges, as is quite frequently done by broad arbitrary standardized rulings of state highway departments.

Specifications issued by the U. S. Bureau of Public Roads prepared in conjunction with the Association of State Highway Officials are given below, as they probably represent the trend of present practice as closely as any data which could be given. Equivalent uniform loads for different spans are given in the chapter on Office Design (p. 1040).

"**Highway Loads for Bridge Floors.** (*American Association of Highway Officials*).—The integral parts of bridge-floor systems, including their direct connections to trusses, girders, and viaduct towers and bents, shall be designed for the maximum stresses produced by truck concentrations. Floor beams, hangers, and all integral members or parts of trusses and girders

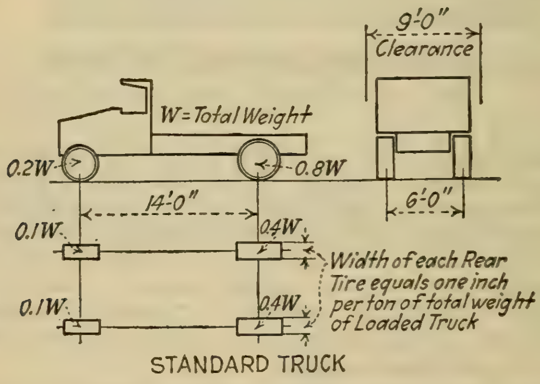


FIG. 55*A*.—Truck dimensions.

subjected to the direct action of floor loads and impacts shall correspondingly be designed for truck concentrations. The truck dimensions and weight distributions used for design purposes shall be those of the typical or standard trucks shown in Fig. 55. These standard trucks are designated by the letter H, followed by a numeral indicating for each class its gross or total weight in tons.

"The class of loading used shall be one of the following:

Loading H-20....................	20-ton trucks
Loading H-15....................	15-ton trucks
Loading H-12½..................	12½-ton trucks or an alternate load of one 15-ton truck
Loading H-10......................	10-ton trucks

"**Highway Loads for Truss and Girders.**—The trusses and girders of bridge spans and the columns of viaduct towers and bents shall be designed for the stresses produced by a load on each traffic lane composed of a uniform load per linear foot of lane with a concentrated load so located longitudinally therein as to produce maximum stresses. The concentrated load shall be considered as uniformly distributed transversely on a line having a length equal to the width of the lane. The standard truck clearance width of 9′ shall be assumed as constituting the width of one traffic lane.

"The class of loading used shall be one of the following:

"*Loading H-20.*—A total load on each traffic lane composed of a uniform load of 600 lb. per linear foot and a single concentrated load of 28,000 lb.

"*Loading H-15.*—A total load on each traffic lane composed of a uniform load of 450 lb. per linear foot and a single concentrated load of 21,000 lb.

"*Loading H-12½.*—A total load on each traffio lane composed of a uniform load of 375 lb. per linear foot and a single concentrated load of 17,500 lb.

"*Loading H-10.*—A total load on each traffic lane composed of a uniform load of 300 lb. per linear foot and a single concentrated load of 14,000 lb.

"NOTE.—Loading H-15 is 75%, loading H-12½ is 62½%, and loading H-10 is 50%, of loading H-20.

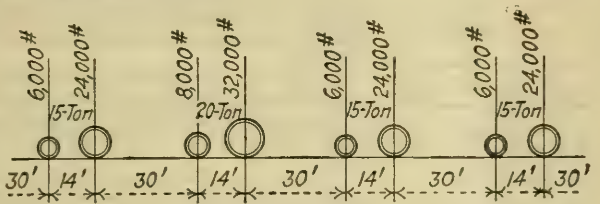


FIG. 55*B*.—Spacing of trucks.

"Loading H-20 is approximately equivalent to the typical truck loading shown in Fig. 55*B*. This loading consists of one 20-ton truck followed by, or preceded by, or both followed and preceded by, a line of 15-ton trucks of indefinite length and assumed to occupy a clearance or lane width of 9'.

"**Electric Railway Loads.**—When highway bridges support electric railway traffic in addition to highway traffic, the railway loading shall be selected with due regard to the class of traffic which may be expected to operate over the railway lines. Special consideration shall be given to the possibility that the freight rolling stock of steam railroads may be operated.

FIG. 55*C*.—Car loadings (electric).

"When not otherwise specified, the electric railway loading on each track shall be a train of two electric cars followed by, or preceded by, or both followed and preceded by, a uniform load. The cars shall be of one of the classes shown in Fig. 55*C*, the designation indicating the total loaded weight of each car, with corresponding axle spacings as indicated. The uniform load per foot of track shall be the weight of the loaded car assumed in th design divided by twice the overall car length. The portion of the roadway width assumed to be occupied by the railway loading shall have a width of 10'.

"For freight car loading, the typical cars shown in Fig. 55*D* may be assumed in the absence of more exact data.

"The railway loading used shall be shown on the stress sheets.

"Highway bridges supporting electric railway traffic shall be designed for the following loading conditions:

"1. The highway loads upon any portion of the roadway area, including that portion occupied by the railway.

"2. The electric railway loads on the car tracks and the highway loads on the remaining traffic lanes.

"**Load Classification of Bridges.**—Bridges shall be classified or rated in relation to their capacities for safely supporting highway loads or a combination of highway and electric railway loads. In general, the division into classes and the corresponding loadings shall be as follows:

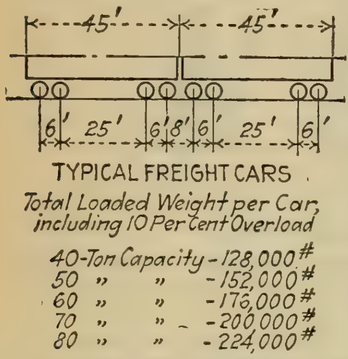


FIG. 55*D*.—Typical freight cars.

"*Class AA.*—Bridges supporting specially heavy traffic units in locations where the passage of such loads is frequent. Class *AA* bridges shall be designed for loading H-20.

"*Class A.*—Bridges supporting normally heavy highway traffic units with occasionally heavy loads. Class *A* bridges shall be designed for loading H-15.

"*Class B.*—Bridges supporting normally light highway traffic units with occasional heavier loads. Class *B* bridges shall be designed for loading H-12½.

"*Class C.*—Bridges of a temporary or semitemporary nature supporting light highway traffic untis. Class *C* bridges shall be designed for loading H-10.

"*Class D.*—Bridges supporting electric railway traffic in addition to highway traffic. The highway loads may correspond to any one of the four classes above specified. The electric railway loads shall be as specified."

These loadings are safe for military purposes, as the following statement of Major General W. M. Black, Chief of Engineers, 1917, will show.

"Our existing ordnance liable to accompany a field army will have its heaviest representative in a 12″ howitzer weighing about 27,000 lb., 18,600 lb. of which are on the front wheels. The base or distance between the front and rear axles is 18′; width of track, 7′ 4″; width of tire, 8″; width of tire shoes, 12″. The howitzer is drawn by a 75-hp. caterpillar tractor weighing 25,000 lb. Comparison with the largest present-day commercial trucks shows that a road or bridge substantial enough for such will suffice for the ordnance load."

Impact.—The extra design load allowance for impact of moving loads is subject to considerable difference in practice, ranging from 0 to 60% of the static weight of the vehicles. Specifications of common practice are given on pages 1040 and 1549.

As a general rule, the following values represent conservative practice in impact allowance.

Floor systems of bridges having timber plank floor surface, 30 to 50%.

Floor systems of bridges and trestles having concrete floor slabs supported by stringers or floor beams, 20 to 30%.

Impact allowance for girders and trusses (see p. 1040).

Impact allowance for floor beam connections (see p. 1040).

For culverts and filled spandrel arch bridges, where the earth cushion between the top of the bridge slab or the arch and bottom

of the road pavement exceeds 1′, the impact allowance disappears (0% impact).

Distribution of Loads.—Rules for current practice in load distribution on concrete slabs, stringers, and floor beams are given on pages 1042 to 1043.

Permissible Stresses in Materials.—This phase of design is quite well established and the common values are given in the chapter on Office Design (p. 1033).

The following table gives safe loads directly for simple structural elements:

Steel I-beams	(pp. 1062 to 1067).
Timber beams	(pp. 1076 to 1077).
Concrete beams	(pp. 1072 to 1074).
Concrete slabs	(pp. 1072 to 1073).
Timber columns	(p. 1078).
Effect of depth of fill on culvert slabs	(pp. 224 and 1075).

Roadway Widths and Clearances.—It is desirable to use the normal roadway width at culverts and bridges so that there is no extra hazard at these points. This general principle can usually be applied without excessive expenditure for culverts and for short-span bridges up to about 25′ span. Beyond 40′ span it is customary to reduce bridge roadway width to the minimum width, which can be safely used by traffic without reduction in speed or danger of side swipe as long-span bridges are a costly element of construction; between 20′ and 40′ spans, roadway widths between minimum and normal are used to meet conditions. Separate sidewalks, at least 5′ wide, are provided for pedestrians in well-settled districts, and are well segregated from road traffic by a raised curb and rail or by placing them outside of trusses or girders. Minimum vertical portal clearance is usually set at 13′ 6″ to 14′ for trucks and 16.0′ for electric cars.

Single-track or one-way bridges are rarely justified except for pioneer roads or local farm roads carrying a very small amount of traffic. Double-track (two-lane) bridges are required on the score of safe passing for practically all roads carrying from 100 to 5000 vehicles daily (10 hour count in summer). Above 5000 vehicles daily a three-lane bridge will serve satisfactorily up to 7000 to 9000 daily (10 hour count in summer) and beyond this limit a four-lane bridge is required. City street bridges should use the normal street width. *In designing bridge roadway widths an allowance of* 60 *years growth in traffic volume is reasonable for types of bridges which cannot be easily widened. For easily widened types a* 20 *to* 30 *year period is ample.* (*See page* 32 *for methods of estimating future traffic volume.*)

For two-lane traffic the A.S.C.E. recommends 20′ minimum roadway. The Hoover Committee on National Safety recommends 22′ minimum where motor busses use the road. For additional traffic lanes, 9′ is added for each additional lane.

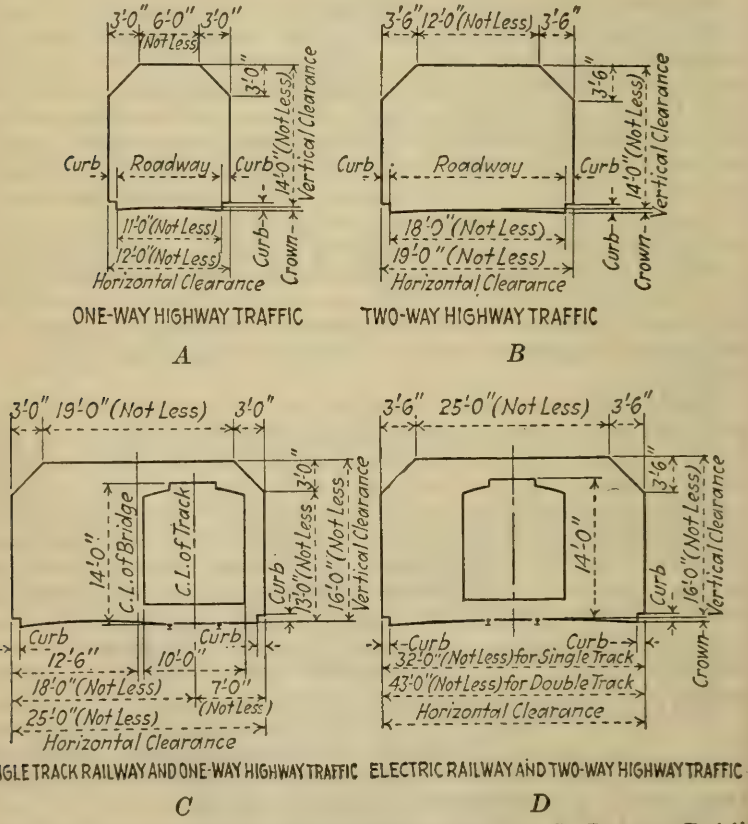
Table 54 gives minimum bridge widths recommended by various authorities for long-span bridges (over 40′ span) on state road systems.

Table 54.—Minimum Roadway Widths
(Bridge spans over 40′)

	One-lane, feet	Two-lane, feet	Extra for additional traffic lanes, feet
U.S. Bureau of Roads	12	18	9
A.S.C.E	12	20	9
Hoover Committee of Safety	..	22	9
State of Iowa[a]	16	18–20	9
State of New York	..	22	10
State of Illinois	..	22	9

[a] For structure less than 40′ span minimum, two-lane traffic roadway width 24′.

The following clearance diagram (Fig. 56) is from the U. S. Bureau of Public Roads Specifications.



Figs. 56*A–D*.—Bridge clearance diagrams. U. S. Bureau Public Roads Standards (1926).

The following quotation from Illinois 1925 practice shows its sliding scale of bridge widths for different classes of roads.

ROADWAYS ON BRIDGES, ILLINOIS PRACTICE, 1925

All grade separations........................Minimum 24′
Bridges and culverts:
I. On state highways
1. 30′ or less between abutments on center line..............................Minimum 30′
2. More than 30′ between abutments on center line..........................Minimum 22′
II. On state-aid roads
1. 12′ or less between abutments on center line..............................Minimum 30′
2. More than 12′ between abutments on center line..........................Minimum 20′
III. On principally traveled roads
1. 12′ or less between abutments on center line..............................Minimum 24′
2. More than 12′ between abutments on center line..........................Minimum 18′
IV. On secondary roads
1. 12′ or less between abutments on center line..............................Minimum 20′
2. More than 12′ between abutments on center line..........................Minimum 16′

NOTE.—For spans of more than 12′ between abutments, hand rails not less than 3′ above the crown of of roadway shall be used.

Type of Structure.—Reasonable type selection depends on ease of construction, appearance, future widening, depth of floor system, foundations, proper use of piers, an economical combination of abutments and different types of superstructures and the utilization of old structures.

Ease of Construction.—Ease and simplicity of construction are desirable, particularly for local road structures under control of the ordinary town superintendent of highways, where expert engineering supervision and competent inspection are not available. For these conditions cast-iron pipe for culverts, rolled-steel, I-beam bridge superstructures with simple concrete slab flooring and mass concrete abutments and wings are preferable types, as they can be abused in construction without much loss of strength. This limitation does not apply to work designed and supervised by expert engineering forces.

Appearance.—Appearance of structure does not often control design on rural highways, but under some conditions, such as parks, cemeteries, village locations, it must be considered. Concrete arches or other types of concrete slab bridges with ornamental balustrades look much better than steel-girder or open-truss bridges.

Future Widening.—Future widening has considerable influence on the type of bridge superstructure and layout of abutments and

wings. As traffic volume often grows rapidly beyond expectec limits, and as local funds are often too small to make it possible tc build the bridge wide enough for all future requirements, it is ofter wise to use a type of bridge that can be widened in the futur without entirely rebuilding. Slabs, stringers, arches, and decl girders can be easily widened. All types of through girders anc trusses cannot be widened without complete rebuilding. Abut ments and wings with their faces in a straight line with step-down vertical plane offsets can be easily extended without loss of previou: work.

Depth of Floor System.—In many cases it is undesirable anc costly to raise the approach grades needlessly and for such condi tions a type of bridge with the least depth of floor system is desirable that is, type design considers floor depth as it affects cost anc suitability of approaches as well as the bridge structure itself. I is a common fault for the bridge designer to think only of the eco nomic design of the structure and to neglect the cost of approache This is particularly true of railroad-grade-crossing-eliminatio structures. Where it is desirable to keep the floor depth to : minimum the most economical designs are usually through girder with floor slab supported directly on the floor beams spaced suffi ciently close so that the concentrated slab load is carried by a least three floor beams. The following table gives the approximat depth of floor systems for different types of bridges of differen roadway widths (H-20 loading) and different spans.

APPROXIMATE DEPTH OF FLOOR SYSTEMS (INCHES)
(Road grade to bottom of superstructure)

Type of superstructure, H-20 loading	Span and roadway widths							
	Spans							
	10′		25′		45′		100′	
	Roadways							
	20′	30′	20′	30′	20′	30′	20′	30′
Concrete slabs	16″	16″	28″	28″				
Steel I-beam stringers	26″	26″	38″	38″	42″	42″		
Concrete T-beam stringers	....	....	31″	31″	62″	62″		
Reinforced-concrete arches	18″	18″	21″	21″	23″	23″	32″	32′
Through plate girder, floor slab, beams and stringer	....	....	....	....	40″	50″	40″	50″
Through plate girders, floor slab and floor beams[a]	....	....	....	....	34″	44″	34″	44″
Through plate girder, floor slab on extra short spaced floor beams[b]	....	....	....	....	28″	38″	28″	38″

[a] This is generally the most economical type of floor system for girde bridges for usual approach conditions (see Fig. 77, p. 290).
[b] This type of floor system is generally economical for long, high approaches.

Foundations. Soils.—Rock or hardpan foundations generally ıdicate rigid frame slab types or arches as an economical solution, rovided there is an adequate height for a reasonable rise ratio. .rches of over 10′ span require piles for any foundation except rock r hardpan and are not usually economical nor conservative design here piles are required, as slight settlement is often disastrous to ıe arch type and adequate pile foundations are very costly. rches of less than 10′ span are often designed with bottom ties ;ewer section) and used on ordinary soil foundations, but such esign (false arches) seems to be an effort to use this type for ›nditions for which it is not primarily suited.

Ordinary foundation soils (clay, sands, gravels, etc.) generally ıake it desirable to select a type of superstructure which transmits s load vertically to the abutments and which will not be materially ımaged by slight settlement. These types are the slab, stringer, : girder bridges with free end supports, and even for these types is desirable to use piles for spans of over 40′ for any soil except ·avel hardpan or rock or for shorter spans where much scour is kely to occur.

Safe foundation loads on soils according to different authorities ·e given in Table 55. For important structures the actual bearing ılue of the soil should be determined as given in the chapter on ıspection (p. 1337).

Piles.—The kind of pile and its safe loading depend on physical ·ound-water conditions and the type of structure to be supported.

In general, it is inadvisable to use untreated timber piles unless ıey are below the permanent ground-water level. Treated timber necessary to resist sea water, borers, and for trestles or where ıe pile is alternately wet and dry. Concrete piles are desirable here piles are not located below permanent ground-water level.

Piles supporting arches or continuous concrete beams or girders hich are injured by even small settlement must be driven to practi- ıl refusal and given a lighter individual load than where they ıpport structures with free ends which are not injured by small ttlement.

Table 56 gives current-practice safe design loads for different kinds piles for different kinds of structures. The actual safe load on les is determined by test loads or by empirical formulas as des- ibed in detail in the chapter on Inspection (p. 1338).

Minimum penetrations, spacing and detail dimensions, and con- ruction manipulation are given in Specifications (p. 1338).

Abutments and Piers.—The use of piers is generally confined to w-height stream crossings where the stream flow is sluggish and e jams are infrequent. The minimum spacings of piers recom- ended by the 1925 Iowa Specifications are as follows:

TABLE 55.—SAFE LOAD ON FOUNDATION SOILS IN TONS (2000 LB.) PER SQUARE FOOT OF BEARING AREA

Authority	Quicksand and alluvial silt	Clean, dry sand	Confined sand and fine gravel	Coarse gravel	Ordinary mixture sand and clay	Soft, damp clay	Dry clay	Cemented gravel or hardpan	Soft rock	Hard rock
Baker's "Foundations"	½	2	4	....	.....	1	4	8	5	25
Hool and Johnston	½–1	2–4	4	....	.....	1–2	4–8	8–10	5–10	15–30
Ketchum	.....	3	4	4–5	2	....	3–4	....	8	20
State of Iowa	.....	....	3	3	1.5	....	3	5	7	25
State of Washington	0–½[a]	3	3–3½	4–7	1½–2	0–2	3–5	5–8	8–15	25
New York Building Code	.....	3	4	4	2	1	4			
Division 4, New York State Highway	½	2	3	4–5	2	1	3–4	6–7	8	20

[a] Confined.

TABLE 56.—DESIGN LOAD ON PILES (TONS PER PILE)

Type of structure	Type of pile	Ordinary load	Extreme maximum load
Slab, girder or trusses	Timber	12–15	20
Slab, girder or trusses	Concrete	25	30
Trestles and viaducts	Timber	15	20
Trestles and viaducts	Concrete	25	30
Arches or continuous girders[a]	Timber	10–12	15
Arches or continuous girders[a]	Concrete	20	25

[a] Piles for these structures to be driven to practical refusal (see p. 1339, Part 2), 25- to 30-ton resistance.

NOTE.—For minimum dimensions of piles see Specifications (p. 1501). Pile spacing generally 3 to 3½′ C. to C. Maximum 4′ without special reinforcing design. Spacing closer than 2½′ worthless. Increase size of footer to get minimum spacing of 2½′.

IOWA SPECIFICATIONS, 1925

"**2. Channel Opening.**—In general, the channel opening provided shall be equal to or greater than that required to discharge the maximum flow safely without damage to the structure from scour.

"*a. For Streams Having Deep Channels.*—In general, the channel opening for structures over streams having deep channels and well-defined banks not subject to overflow shall be of such length that it will entirely span the main channel. In streams in which the banks are subject to possible future widening, provision shall be made for such conditions by an increase in span length.

"*b. For Streams Having Low Banks and Subject to Overflow.*—On streams having low banks which are subject to overflow and where the approach to the structure is above high water, the waterway opening provided shall be sufficient to discharge the flood area at safe velocities against scour and

the main channel openings shall be of sufficient length to discharge débris and ice efficiently.

. . .

"**4. Pier Spacing.**—On streams having a difference in height between high and low water exceeding 6′, the main channel piers of multiple-span bridges shall not be spaced closer to each other than four times the difference of height between high and low water. The above shall not apply to a stage which is caused by backwater."

Where piers are permissible, they generally result in the use of a series of slab or stringer superstructures in place of single-span girders or trusses. They also permit multiple arches which are pleasing in appearance.

For spans of less than 45 feet piers must be used with caution but where it is certain they will not cause clogging they often result in a material reduction in cost due to less floor depth and cheaper superstructures. They are particularly desirable for low height openings in rock or hardpan foundations. This same general statement applies to the use of double box culverts with central pier wall where a concrete floor is desirable to prevent scour on high velocity small streams.

Mass concrete is common practice for short-span (less than 50′) bridge abutments and piers, and is preferable for even high long-span structures, although reinforced-concrete buttress abutments are often used for high abutments. Abutment footings are usually carried down at least 4′ below the stream bed in ordinary soils, and pier footing at least 6′. Where hard rock is encountered, the footing is usually 6″ to 1′ below the surface of the rock in order to key in properly, and where soft rock or hardpan is encountered the bottom of the footing is usually at least 2′ below the surface of the hard strata. Figures 69 to 78 show common practice for mass abutments and piers for bridges up to 100′ spans.

Superstructures.—Table 57 shows the general limits of span for which different types of bridge may be considered in making

TABLE 57.—LIMITATIONS OF USE OF DIFFERENT TYPES OF CULVERTS AND BRIDGES

Type	Range in span
Pipes	12–42″
Box culverts	2–10′
Reinforced-concrete slabs	5–25′
Steel I-beam stringers	10–55′
Reinforced-concrete stringers (T-beams)[a]	20–40′
Reinforced-concrete through girders	20–50′
Reinforced-concrete arches (hardpan or rock foundations)	All spans above 6′
Steel-plate girders (deck or through)[b]	40–100′
Steel pony trusses	40–100′
Steel-riveted through truss	Above 90′
Steel pin connected through truss	Above 150′
Timber structures:	
Trestle spans	10–25′
Truss spans	Above 25′

[a] T-beam reinforced-concrete stringers not economical where forming is difficult due to soft foundations or high abutments.

[b] Deck girders rarely advisable due to clearance limitations. Where they are permissible, they are generally cheaper than the through type.

alternate estimates of cost. These alternate estimates of costs must include initial cost plus maintenance and renewal costs, considering a reasonable length of life for the different types. Maintenance painting for exposed steel for 1925 cost conditions amounts to about 50 to 70 cts. per ton per year average, which, capitalized at 5%, is equivalent to approximately \$10 to \$15 per ton which must be added to the initial cost of construction to determine final comparative costs. For steel weights see bridge steel diagrams, Chap. IX (p. 652). Renewal costs are very indefinite, as the comparative life of steel and concrete structures cannot be closely approximated. If steel structures are well maintained, their lives should compare favorably with concrete or steel encased in concrete. As a matter of fact, the maintenance is often neglected, which materially shortens the life of steel bridges.

Utilization of Old Structures.—The proper utilization of old structures, either in whole or in part, has a decided effect on materially reducing the cost of bridge replacements. There is too much tendency towards complete abandonment and entire new construction. To illustrate the value of careful utilization of well-built parts of old structures we quote the following paragraph from the report of the Bridge Engineer of N. Y. State Highway Dept. Div. 4 for 1926:

"Thirty-five small span bridges (less than 45′ span) have been designed in 1926. In thirteen cases it was possible to utilize some part of the old structure and such action has reduced construction cost of these bridges approximately \$30,000."

Examples of common methods of utilizing old structures are given in Chap. XIV, pages 1013 to 1020.

Consideration of utilizing the old existing structure completes the factors which determine the selection of economic and suitable type of bridge to be used. The typical design report on page 327 illustrates the application of the principles discussed for bridge type selection. The quick cost estimating diagrams, pages 310 to 326, are helpful in making comparative cost estimates of bridges. Desirable culvert types and relative costs are given on page 213.

Surface of Bridge Floors.—On rural highways, bridge floors are usually constructed of reinforced concrete, the upper 3″ of which is considered as the pavement surface and is not considered as adding anything to the strength of the slab. This upper 3″ is, however, generally molded monolithic with the slab proper and is reinforced with standard paving mesh. A recent modification of this standard procedure constructs the standard bridge floor slab first, waterproofs the top, and then constructs a thin pancake concrete surface (see Fig. 76). The older practice of monolithic molding is much superior, and when a new surface is needed some form of asphaltic concrete may be used on thin blocks on the top of the pitted concrete floor. Any thin layer of concrete will crack up readily under heavy loading unless it is at least 5″ to 6″ thick well reinforced and there is no advantage in eventually renewing this pancake and replacing at the same elevation, as the road pavements on both sides of the bridge will in the future be capped and raised in the same manner as recommended for floor repair: the original design should provide

for a small increase in future dead load to provide or the future floor capping (25 lb. per square foot). Thin asphalt block or bituminous concrete makes the most satisfactory renewable surface (see Specifications, p. 1563).

Bridge Parapets.—For city and special bridges extremely ornate balustrades are used but for rural highways it is desirable to use the simple types shown in Figs. 69 to 76. Of these types the level-top, paneled parapet is generally the most satisfactory as it fits in well with the straight-line approach guard railing and it is comparatively easy to finish properly which is important considering the class of masons generally employed on road work. The type shown in figure 76*A* is all right provided there is no approach straight-line guide rail but it does not look well in conjunction with approach rail.

Parapets along sidewalks should be from 38 to 40″ above the walk to insure ample protection.

Condemnation and Repair of Weak Bridges.—For data on this phase of bridge work the reader is referred to Chap. XII, page 779.

Protection from Scour.—Where the natural stream velocity is high or where it is necessary to restrict the bridge opening with a resultant high velocity which causes bank scour, rip-rap or other protection must be provided. Specifications for rip-rap are given on page 1506.

Iowa 1925 Specifications give the following maximum velocities requiring special bank protection for different natural soils:

"**Restricted Waterways.**—If the area of waterway provided is not sufficient to discharge the maximum flood flow at mean velocities less than the following, ample provision shall be made in the design for protection against scour:

a. Sand, alluvial soil, and soft clay.................. 4′ per second
b. Firm clay, loose stones, or boulders.............. 6′ per second
c. Rock, shale, or cemented clays.................. 8′ per second."

Rip-rap protection reduces scour. According to Trautwine, a velocity of 8 m.p.h. or 12′ per second will not derange quarry rubber stones exceeding ½ cu. ft. deposited around piers or abutments. Specifications for rip-rap are given on page 1506. If the natural stream velocity is not over 10′ per second the span is usually regulated so that the velocity under the bridge during freshets will not exceed 10′ per second. If the natural stream velocity of flow at the bridge site is not known, it can be approximated roughly for small streams by the formula from Table 52 (p. 195).

Paved Fords.—For wide, shallow arroyos of the arid regions of the West, paved fords are in general use. These channels carry water only during sudden severe storms, and to provide structures large enough to carry the sudden large infrequent flows would be practically prohibitive in cost. The road across an arroyo is kept slightly below the natural elevation of the wash and is paved with concrete, cobblestone, or timber (see sketch). The alignment is straight and the location of the pavement is shown during flood by four marking posts, two at each end, which also indicate the depth of water, so that it can be used even if covered with water, unless the depth is too great for safety, which can be determined by the

gages on the range posts. As the concrete is below the bottom o: the stream, no scour occurs and generally a thin layer of sand is deposited on the concrete, which can be easily cleaned off with a road machine.

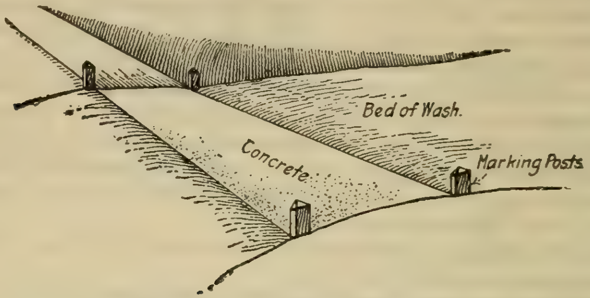


FIG. 57.—Paved ford.

Example of Current Practice in Design.

Culverts (pp. 214 to 236).

Small-span bridges (pp. 237 to 309).

Pipe Culverts.—The pipe culverts in common use are as follow (see Figs. 59 to 63, pp. 215 to 219) for typical pipe):

Corrugated metal	semipermanent constructio
Vitrified tile	semipermanent constructio
Reinforced-concrete pipe	semipermanent constructio
Vitrified tile incased in concrete	permanent construction
Reinforced-concrete pipe cradled in concrete	permanent construction
Cast-iron pipe	permanent construction

These types of culverts are suitable on firm foundations and ar generally economical for small drainage areas. The relative cos will fluctuate for each contract, which makes it impossible to genera ize as to the economy of selection.

Box Culverts.—The two general types favored are the plain mas onry or concrete bottom and side wall with reinforced cover slat and the lighter box reinforced on all sides (see Figs. 65 and 67)

Circular-opening culverts are sometimes used (see Fig. 68).

Relative Economy of Culverts.—Comparative estimates of cos must be made for each contract, but to give a general idea of th method of economical selection Table 58 is inserted for 1926 cos conditions prevailing in western New York.

The semipermanent types should not be used on high-clas improvements except for driveway culverts.

Comparative estimates similar to Table 58 furnish a rationa basis for judgment, provided only the permanent types are com pared and that the comparison is made for each contract considerin the special conditions prevailing due to location, market quotation on materials, and local materials available.

For conditions similar to Table 58, western New York, 1926, permanent pipe culverts are not economical over an 18″ diameter. For drainage areas requiring a culverts waterway area of over [illegible] sq. ft. the box type is preferable. Of the box types the simple mass concrete structures are more satisfactory on firm foundation soils, considering construction difficulties, than the thin-wall reinforced type, although they cost somewhat more than the thin side-wall type. This, however, is a matter of personal judgment.

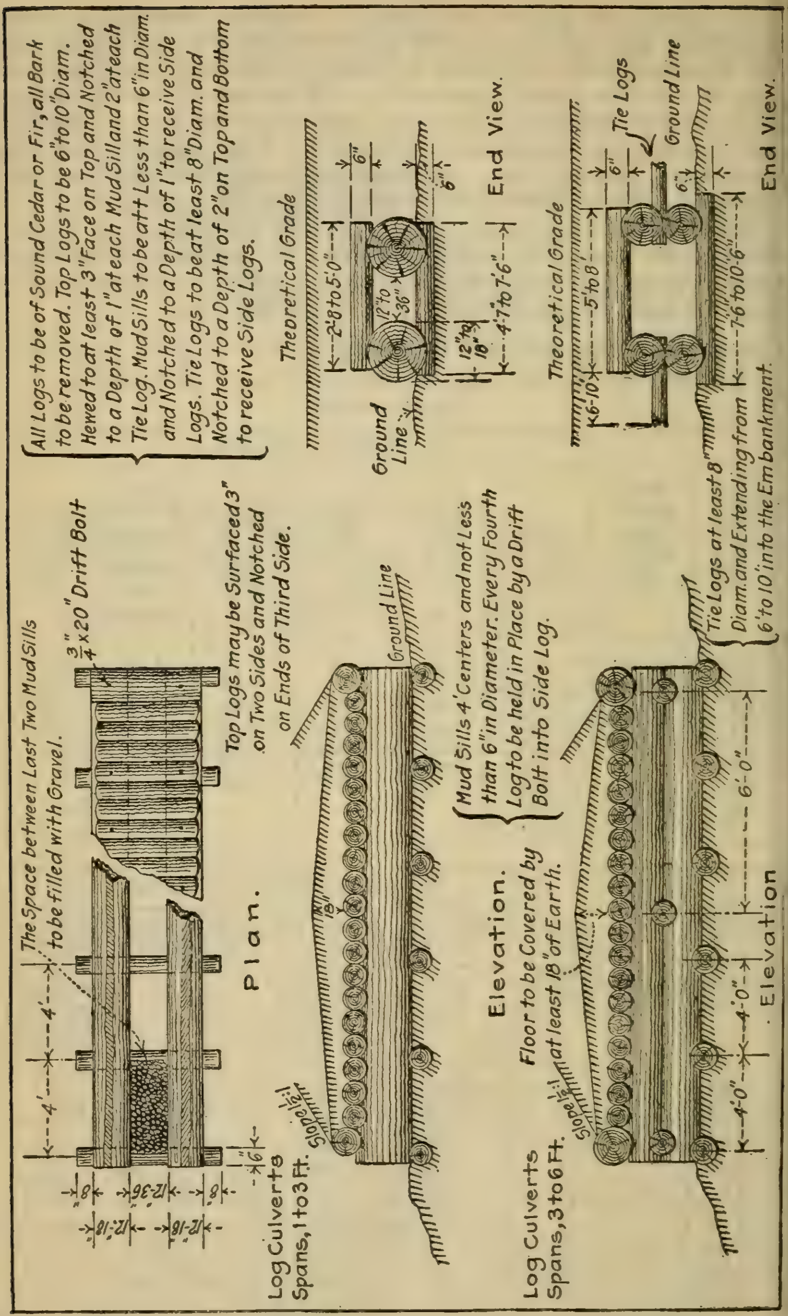
The thin-wall type, reinforced in bottom, sides, and top, is preferable to the mass type under very deep fills or on soft foundations where bottom slab action occurs or where negative corner bending moments must be considered. (See figure page 224).

Table 58.—Approximate Relative Cost of Pipe and Box Culverts 30′ Long Including Headwalls (Exclusive of Excavation)

Size culvert pipe, inches	Area waterway, square feet	Style of construction					
		Corrugated metal	Vitrified tile	Vitrified tile incased in concrete	Reinforced-concrete pipe	Reinforced-concrete pipe cradled in concrete	Cast-iron pipe
12	0.78	$ 60	$ 50	$ 65	$ 75	$ 90	$100
14	1.07	70	60	75	80	95	130
18	1.76	90	80	110	100	130	170
24	3.14	120	120	160	135	175	260
30	4.88	140	180	230	180	230	
36	7.05	170	260	310	240	290	
42	9.60	200	. . .	. . .	300	360	
48	12.52	230					

Size culvert opening span-height, feet	Area waterway, square feet	Style of construction, concrete boxes			
		Mass concrete bottom, and sides (Fig. 65)		Thin reinforced sides and bottom (Fig. 66)	
		Total cost	Cost per square foot waterway	Total cost	Cost per square foot waterway
2 by 1.5	3	$160	$57		
2 by 2	4	190	50	$150	$35
3 by 2	6	210	37		
3 by 3	9	260	30	200	22
3 by 4	12	300	26		
4 by 2	8	250	31	230	30
4 by 3	12	300	25		
4 by 4	16	340	21	300	20
5 by 3	15	350	23		
5 by 4	20	400	20	350	17
5 by 5	25	450	18		

The following cuts illustrate typical practice in small-culvert and short span bridge design.


The Space between Last Two Mud Sills to be filled with Gravel.
3/4" x 20" Drift Bolt
4'
8"
12"-36"
12"-18"
6"
Plan.
Top Logs may be Surfaced 3" on Two Sides and Notched on Ends of Third Side.
All Logs to be of Sound Cedar or Fir, all Bark to be removed. Top Logs to be 6" to 10" Diam. Hewed to at least 3" Face on Top and Notched to a Depth of 1" at each Mud Sill and 2" at each Tie Log. Mud Sills to be at Less than 6" in Diam. and Notched to a Depth of 1" to receive Side Logs. Tie Logs to be at least 8" Diam. and Notched to a Depth of 2" on Top and Bottom to receive Side Logs.
Theoretical Grade
Ground Line
2'-8 to 5'-0"
12" to 36"
12" to 18"
4'-7 to 7'-6"
6"
End View.
Log Culverts Spans, 1 to 3 Ft.
Slope 1½:1
18"
Ground Line
Elevation.
Mud Sills 4' Centers and not Less than 6" in Diameter. Every Fourth Log to be held in Place by a Drift Bolt into Side Log.
Floor to be Covered by at least 18" of Earth.
Log Culverts Spans, 3 to 6 Ft.
Slope 1½:1
4'-0"
4'-0"
6'-0"
Elevation
Tie Logs at least 8" Diam. and Extending from 6' to 10' into the Embankment.
Theoretical Grade
6'-10
5' to 8
6"
Tie Logs
Ground Line
7'-6 to 10'-6"
End View.

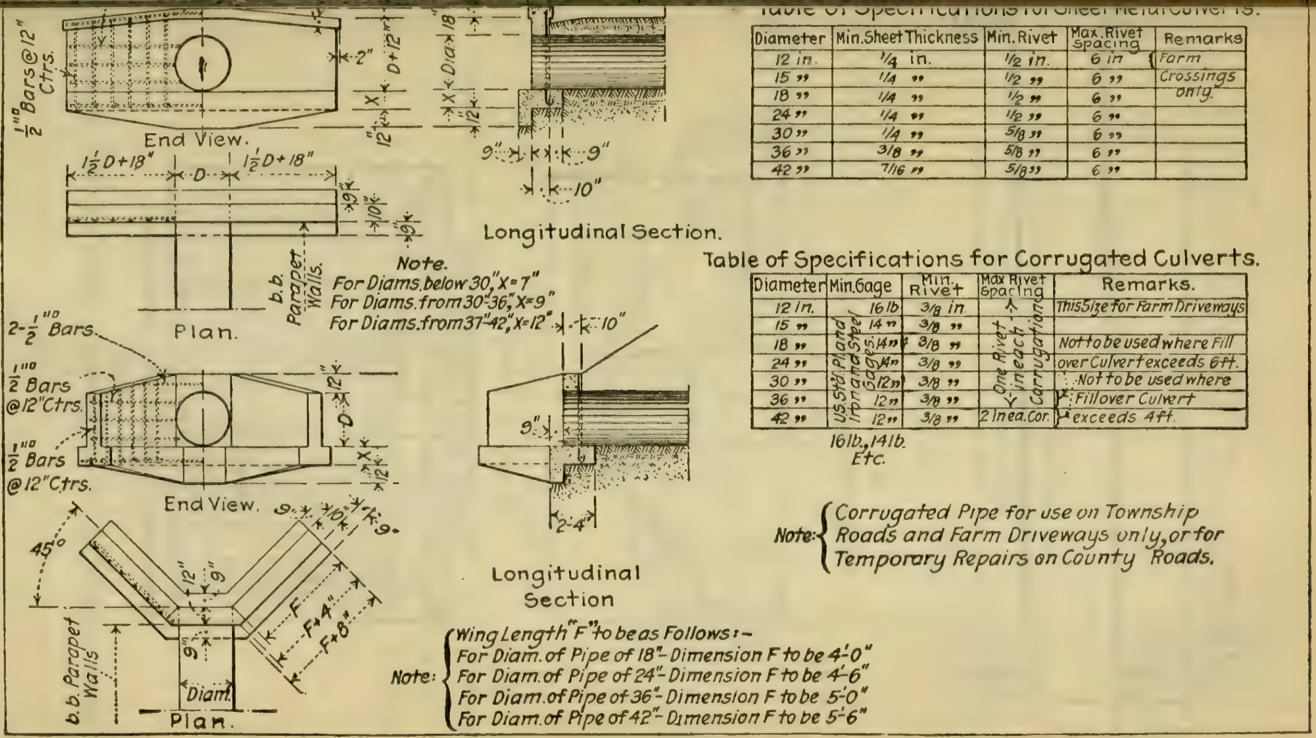


Table of Specifications for Sheet Metal Culverts.

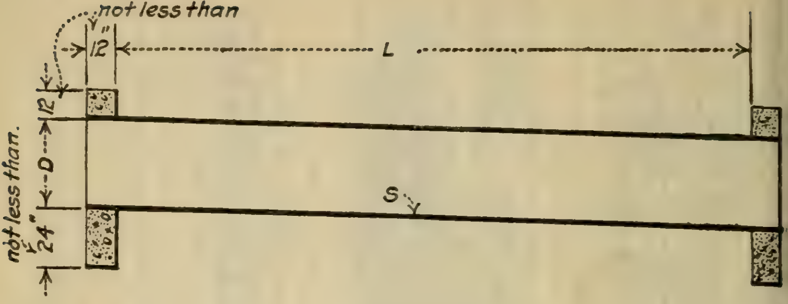
Diameter	Min. Sheet Thickness	Min. Rivet	Max. Rivet Spacing	Remarks
12 in.	1/4 in.	1/2 in.	6 in	Farm Crossings only.
15 "	1/4 "	1/2 "	6 "	
18 "	1/4 "	1/2 "	6 "	
24 "	1/4 "	1/2 "	6 "	
30 "	1/4 "	5/8 "	6 "	
36 "	3/8 "	5/8 "	6 "	
42 "	7/16 "	5/8 "	6 "	

Table of Specifications for Corrugated Culverts.

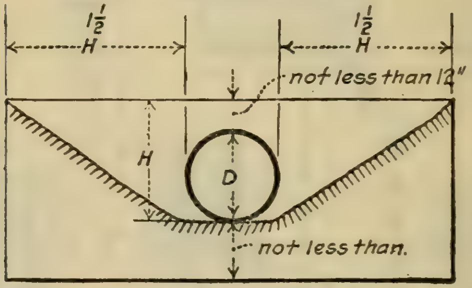
Diameter	Min. Gage	Min. Rivet	Max Rivet Spacing	Remarks.
12 in.	16 lb	3/8 in.	One Rivet in each Corrugation	This Size for Farm Driveways
15 "	14 "	3/8 "		
18 "	14 "	3/8 "		Not to be used where Fill over Culvert exceeds 6 ft.
24 "	14 "	3/8 "		
30 "	12 "	3/8 "		Not to be used where Fill over Culvert exceeds 4 ft.
36 "	12 "	3/8 "		
42 "	12 "	3/8 "	2 in ea. Cor.	

U.S. Std. Pl. and Iron and Steel Gages. 16 lb., 14 lb. Etc.

FIG. 59.—Metal pipe culverts. State of Iowa.



Longitudinal Section



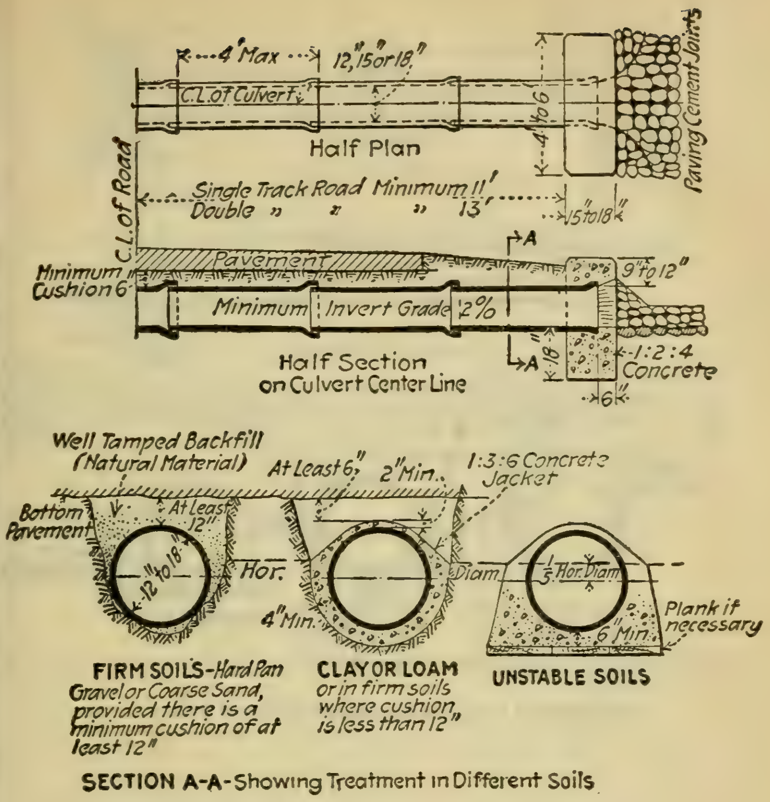
End Elevation.

TABLE OF PROPERTIES.

Diameter "D"	Slope "S"	Capacity, Cu. Ft. per Sec.	Concrete Cu. Yds.
10"	0.048	1.64	1.75
12"	0.033	2.36	2.0
14"	0.025	3.21	2.3
16"	0.020	4.20	2.6
18"	0.016	5.31	2.9
20"	0.012	6.54	3.2
24"	0.010	9.42	3.8
30"	0.007	14.73	4.9
36"	0.005	21.21	6.1
Velocity = 3.0 Ft. per Sec. "n" = 0.027			

Quantities Figured from Minimum Dimensions.

FIG. 60.—Corrugated metal culverts. State of New Hampshire



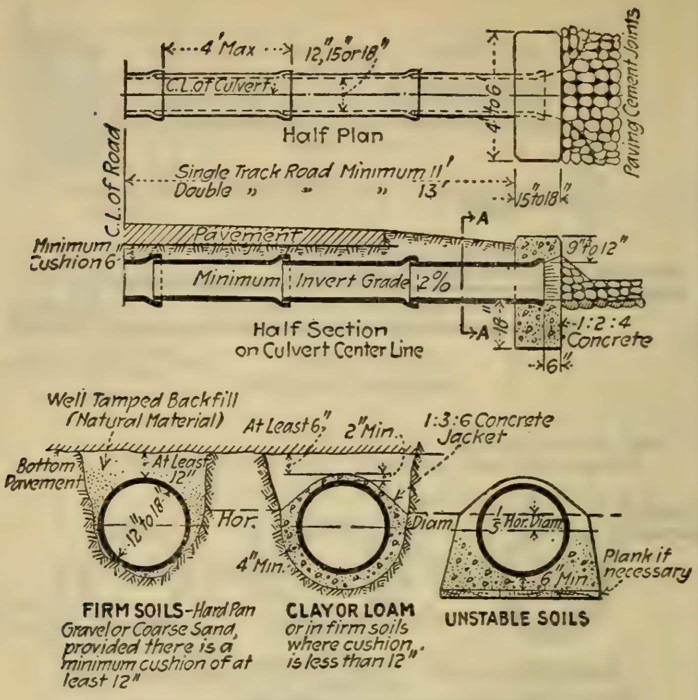
Approximate Weight, Dimensions, Etc. of Standard Sewer Pipe

Calibre, in.	Price per foot	Weight per foot, lbs.	Depth of socket, in.	Annular space, in.	Thickness, in.
12	\$1.35	45	2¼	½	1
15	1.80	60	2½	½	1⅛
18	2.50	85	2¾	½	1¼
20	3.00	100	3	½	1 3/3
22	4.00	130	3	½	158
24	4.50	140	3¼	½	158

Double Strength Pipes

Calibre, in.	Price per foot	Weight per foot, lbs.	Depth of socket, in.	Annular space, in.	Thickness, in.
15	\$1.80	75	2½	½	1¼
18	2.50	118	2¾	½	1½
20	3.00	138	3	½	1⅔
22	4.00	157	3	½	1 5/6
24	4.50	190	3¼	½	2

Fig. 61.—Typical vitrified pipe culverts.



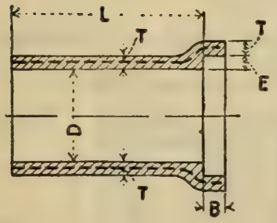


TABLE OF DIMENSIONS AND REINFORCEMENT FOR PIPE

Table of Dimensions

D Inches	L-Max. Feet	T Inches	B-Min. Inches	E Inches
12	4	2	2½	2½
15	4	2	2½	2½
18	4	2½	3	3
24	4	3	3	3½
Effective Area of Circumferal Reinforcement Per Foot Length of Pipe				
12	0.058 Sq. Inches			
15	0.058 " "			
18	0.080 " "			
24	0.126 " "			
Approximate Weight Per Linear Foot of Pipe				
12	90 lbs			
15	110 "			
18	170 "			
24	260 "			

Fig. 62.—Typical reinforced concrete pipe culverts.

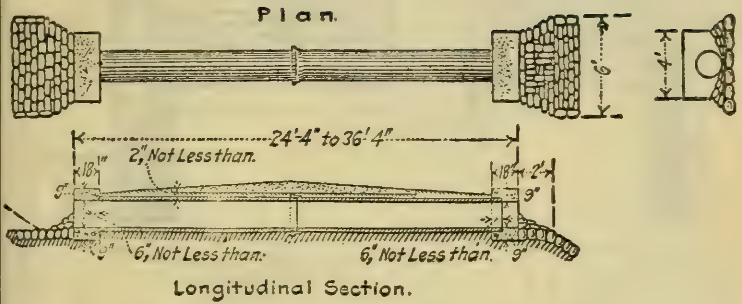
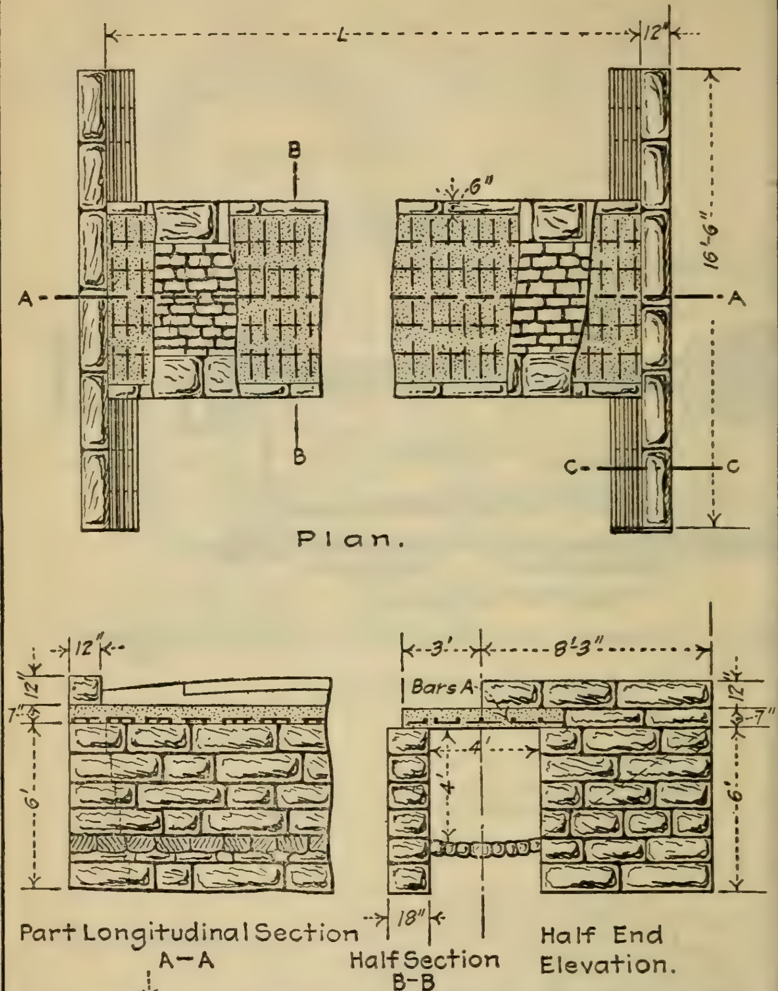
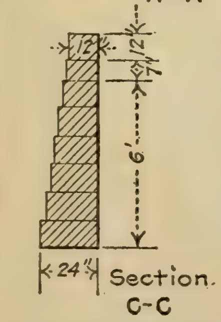


FIG. 63.—Cast iron pipe culvert. New York State standard.

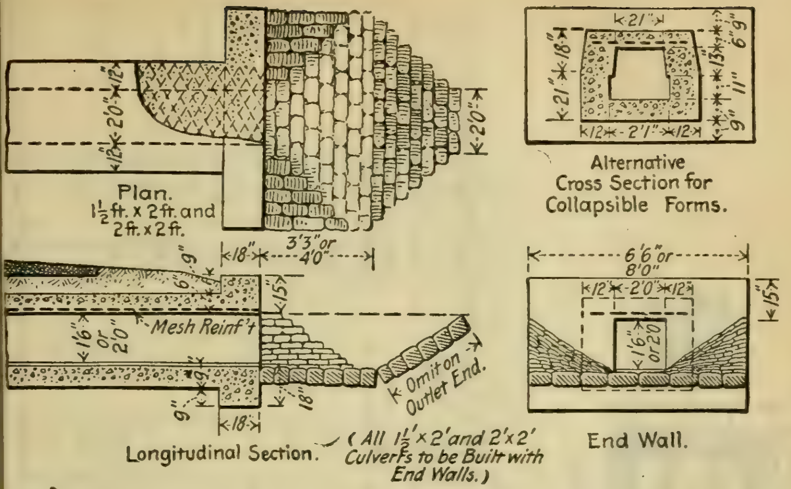


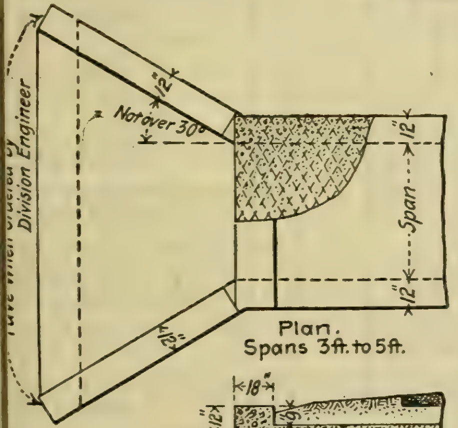


Depth Fill	Length L.	Bars A ½" Sq. Spacing	Bars A ½" Sq. Number	Bars A ½" Sq. Length	Masonry Cu. Yds.	Concrete Cu. Yds	Paving
1	21'-0"	7"	40	5'-9"	24.3	3.0	10.2
2	21'-6"	6½"	43	"	24.6	3.0	10.4
3	24'-6"	7½"	43	"	26.6	3.4	11.8
4	27'-6"	7"	51	"	28.6	3.8	13.1
5	30'-6"	7"	56	"	30.6	4.2	14.4
6	33'-6"	6½"	66	"	32.6	4.6	15.8
8	39'-6"	6"	83	"	36.6	5.4	18.4

TABLE OF QUANTITIES 4'x4' CULVERT

FIG. 64.—Typical masonry culvert. State of New Hampshire.





Span	Thickness of Slab	Thickness of Abutment	Mesh Reinforcement, Lbs. per sq. ft.
2'0"	6"	12"	0.6
3'0"	6"	12"	1.2
4'0"	6"	12"	1.2
5'0"	8"	12"	1.2

Table of Dimensions.

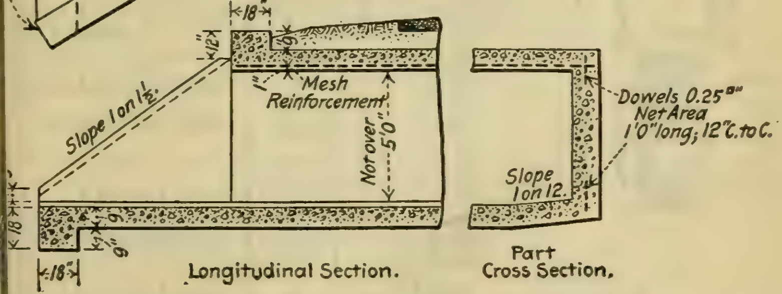
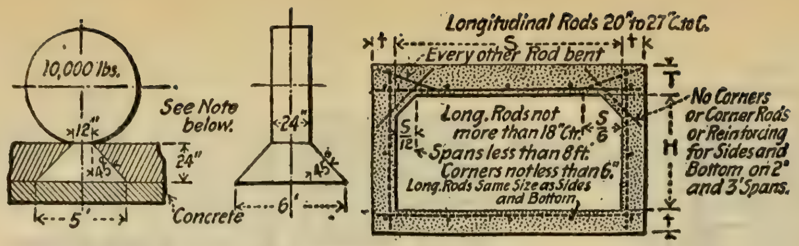


FIG. 65.—New York State small box culverts. Suitable for m foundation soils. On soft soils use reinforced culverts, ig. 66, page 222 and Fig. 67, page 224.

Note.—For effect of deep fills on culvert design see page 224. hese culverts safe for following maximum depth of fill over top of ab assuming firm foundation soil. 2′ span no limit, 3′ span 30 . limit, 4′ span, 20 ft., 5′ span 13 ft. limit.



Assumption for Live Load. Cross Section of Culvert.

FIG. 66.

TABLE FOR STANDARD CULVERTS

Loading 15-ton road roller, 10,000 lbs. on each wheel. Unit stresses 16,000 lbs. for steel, 600 lbs. for concrete, 0.7% of steel. Los Angeles Co. Highway Com., A. E. Loder, Chief Eng.

				Top reinforcement			Corner reinforcement			Side walls reinforcement			Bottom reinforcement			Quan. per lineal ft. box		
D[1]	H[2]	T[3]	t[4]	Size	Spc.	Lgth.	Size	Spc.	Lgth.	Size	Spc.	Lgth.	Size	Spc.	Lgth.	C. yds. con.	Steel lb.	
8"	1'	4"	4"	3/8"	8"	2'- 6"										.091	3.70	2-span
8"	2'	4"	4"	3/8"	8"	2'- 6"										.115	3.70	
8"	1'	5½"	5"	3/8"	5"	3'- 9"										.155	7.17	
8"	2'	5½"	5"	3/8"	5"	3'- 9"										.186	7.17	3'-span
8"	3'	5½"	5"	3/8"	5"	3'- 9"										.216	8.12	
8"	1'	6"	5"	½"	8"	4'- 8"	3/8"	16"	1'-6"	3/8"	16"	1'-9"	3/8"	16"	4'- 8"	.204	12.83	
8"	2'	6"	5"	½"	8"	4'- 8"	3/8"	16"	1'-6"	3/8"	16"	2'-9"	3/8"	16"	4'- 8"	.235	13.55	4'-span
8"	3'	6"	5"	½"	8"	4'- 8"	3/8"	16"	1'-6"	3/8"	16"	3'-9"	3/8"	16"	4'- 8"	.266	15.22	
8"	2'	6½"	5"	½"	7"	5'- 8"	3/8"	14"	1'-6"	3/8"	14"	2'-9"	3/8"	14"	5'- 8"	.278	17.91	
8"	3'	6½"	5"	½"	7"	5'- 8"	3/8"	14"	1'-6"	3/8"	14"	3'-9"	3/8"	14"	5'- 8"	.309	19.68	5'-span
8"	4'	6½"	5"	½"	7"	5'- 8"	3/8"	14"	1'-6"	3/8"	14"	4-9"	3/8"	14"	5'- 8"	.339	20.49	

8″	2′	7½″	6″	½″	6″	6′-10″	⅜″	12″	1′-9″	⅜″	12″	3 -0″	⅜″	12″	6′-10″	.373	23.23	6′-span
8″	3′	7½″	6″	½″	6″	6 -10″	⅜″	12″	1′-9″	⅜″	12″	4′-0″	⅜″	12″	6′-10″	.410	25.14	
8″	4′	7½″	6″	½″	6″	6′-10″	⅜″	12″	1′-9″	⅜″	12″	5′-0″	⅜″	12″	6′-10″	.448	26.10	
8″	2′	8½″	6″	⅝″	8″	8′-10″	½″	16″	2′-0″	½″	16″	3′-2″	½″	16″	8′-10″	.494	38.32	8′-span
8″	3′	8½″	6″	⅝″	8″	8′-10″	½″	16″	2′-0″	½″	16″	4′-2″	½″	16″	8′-10″	.531	41.30	
8″	4′	8½″	7″	⅝″	8″	9′- 0″	½″	16″	2′-0″	½″	16″	5′-2″	½″	16″	9′- 0″	.628	43.02	
8″	5′	8½″	7″	⅝″	8″	9′- 0″	½″	16″	2′-0″	½″	16″	6′-2″	½″	16″	9 - 0″	.671	46.00	
8″	2′	10″	7″	⅝″	6½″	11′- 0″	½″	13″	2′-6″	½″	13″	3′-3″	½″	13″	11′- 0″	.700	54.90	10 -span
8″	3′	10″	7″	⅝″	6½″	11′- 0″	½″	13″	2′-6″	½″	13″	4′-3″	½″	13″	11′- 0″	.742	58.17	
8″	4′	10″	7″	⅝″	6½″	11′- 0″	½″	13″	2′-6″	½″	13″	5 -3″	½″	13″	11′- 0″	.786	59.74	
8″	5′	10″	8″	⅝″	6½″	11′- 2″	½″	13″	2′-8″	½″	13″	6′-4″	½″	13″	11′- 2″	.900	63.90	
8″	6′	10″	8″	⅝″	6½″	11′- 2″	½″	13″	2′-8″	½″	13″	7′-4″	½″	13″	11′- 2″	.949	65.47	
8″	7′	10″	8″	⅝″	6½″	11′- 2″	½″	13″	2′-8″	½″	13″	8′-4″	½″	13″	11′- 2″	1.000	68.74	
8″	8′	10″	8″	⅝″	6½″	11′- 2″	½″	13″	2′-8″	½″	13″	9′-4″	½″	13″	11′- 2″	1.048	70.31	
8″	2′	11″	8″	⅝″	6″	13′- 2″	½″	12″	3′-0″	½″	12″	3′-7″	½″	12″	13′- 2″	.916	69.31	12′-span
8″	3′	11″	8″	⅝″	6″	13′- 2″	½″	12″	3′-0″	½″	12″	4′-7″	½″	12″	13′- 2″	.965	72.71	
8″	4′	11″	8″	⅝″	6″	13′- 2″	½″	12″	3′-0″	½″	12″	5′-7″	½″	12″	13′- 2″	1.014	74.41	
8″	5′	11″	8″	⅝″	6″	13′- 2″	½″	12″	3′-0″	½″	12″	6′-7″	½″	12″	13′- 2″	1.063	77.81	
8″	6′	11″	9″	⅝″	6″	13′- 4″	½″	12″	3′-0″	½″	12″	7′-6″	½″	12″	13′- 4″	1.205	79.94	
8″	7′	11″	9″	⅝″	6″	13′- 4″	½″	12″	3′-0″	½″	12″	8′-9″	½″	12″	13′- 4″	1.261	83.34	
8″	8′	11″	9″	⅝″	6″	13′- 4″	½″	12″	3′-0″	½″	12″	9′-6″	½″	12″	13′- 4″	1.316	85.04	
8″	9′	11″	9″	⅝″	6″	13-′ 4″	½″	12″	3′-0″	½″	12″	10′-6″	½″	12″	13′- 4″	1.372	88.44	
8″	10′	11″	9″	⅝″	6″	13′- 4″	½″	12″	3′-0″	½″	12″	11′-6″	½″	12″	13′- 4″	1.427	90.14	

[1] Depth of fill.
[2] Height of culvert.
[3] Thickness of top.
[4] Thickness of bottom and sides.

NOTE: This table is calculated for a minimum fill of 8 in. of rocks over culvert slabs and is correct for all fills up to 6 ft. in height.

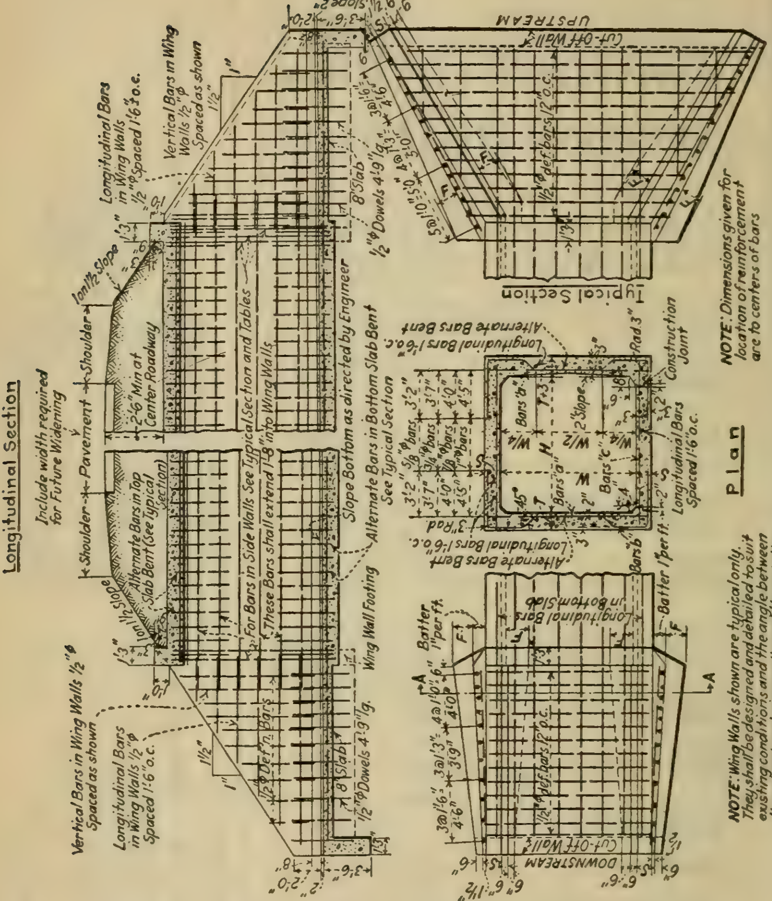
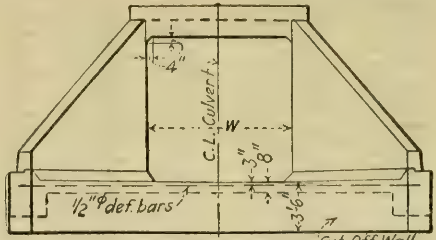
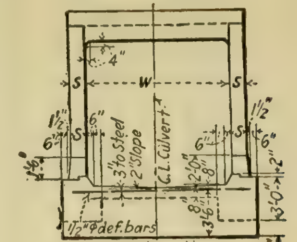


FIG. 67.—Reinforced box culverts N. Y. State, 1926.

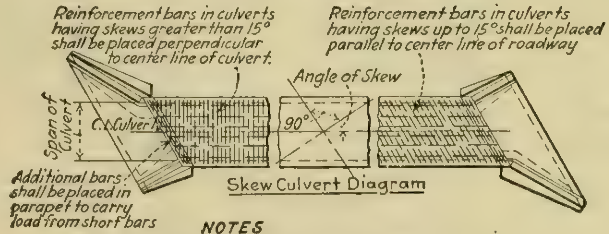
Note.—Suitable on soft foundations or under very deep fills Not a good design for firm soils under light fills.



End Elevation
Upstream

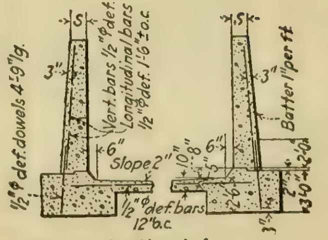


End Elevation
Downstream



Skew Culvert Diagram

WING WALLS		
SIZE	S	F
6x4	Make "S" same as side wall dimension in culvert table	7½"
6x5		9"
6x6		10½"
7x4		7½"
7x5		9"
7x6		10½"
7x7		1'0"
8x4		7½"
8x5		9"
8x6		10½"
8x7		1'0"
8x8		1'2"
10x4		7½"
10x5		9"
10x6		10½"
10x7		1'0"
10x8		1'2"
10x9		1'4"
10x10		1'6"



Section A-A

NOTES

Concrete in Culverts shall be 1:2:3½ Mix
Reinforcing bars shall be Medium Open Hearth Steel
Depth of fill shall be measured at crown of roadway
The longitudinal bars shown on the typical section are for a 10'x10' culvert. For culverts of different size, the number of longitudinal bars shown in the table shall be used. The tabular number is for one top bottom or side slab in culverts where "H" is 4' or 5' one outside longitudinal bar shall be used in each side in place of the two outside bars shown in the typical section.

FIG. 67.—(Continued.)

TABLE OF SLAB THICKNESSES AND REINFORCEMENT FOR CULVERTS

Inside culvert dimensions		Depth of fill over top of culverts — Between 2′–6″ and 8 ft. deep												
		Top & bottom slabs							Side slabs					
		Thickness, T	Reinforcement						Thickness, S	Reinforcement				
			Transverse				Longitudinal			Vertical			Longitudinal	
W	H		Size φ	Spacing	Length bars "a"	Length bars "b"	No.	Size φ		Size φ	Spacing	Length bars "c"	No.	Size φ
6′	4′	9″	5/8″	6″	7′–0″	14′–0″	7	1/2″	9″	1/2″	12″	5′–3″	4	1/2″
6′	5′	9″	5/8″	6″	7′–0″	14′–0″	7	1/2″	0″	1/2″	7 1/2″	6′–3″	4	1/2″
6′	6′	9″	5/8″	6″	7′–0″	14′–0″	7	1/2″	9″	1/2″	5 1/2″	7′–3″	6	1/2″
7′	4′	10″	3/4″	7 1/2″	8′–2″	16′–3″	8	1/2″	10″	1/2″	12″	5′–5″	4	1/2″
7′	5′	10″	3/4″	7 1/2″	8′–2″	16′–3″	8	1/2″	10″	1/2″	8 1/2″	6′–5″	4	1/2″
7′	6′	10″	3/4″	7 1/2″	8′–2″	16′–3″	8	1/2″	10″	1/2″	6″	7′–5″	6	1/2″
7′	7′	10″	3/4″	7 1/2″	8′–2″	16′–3″	8	1/2″	10″	1/2″	4 1/2″	8′–5″	6	1/2″
8′	4′	11″	3/4″	6″	9′–4″	17′–8″	9	1/2″	11″	1/2″	12″	5′–7″	4	1/2″
8′	5′	11″	3/4″	6″	9′–4″	17′–8″	9	1/2″	11″	1/2″	9 1/2″	6′–7″	4	1/2″
8′	6′	11″	3/4″	6″	9′–4″	17′–8″	9	1/2″	11″	1/2″	6 1/2″	7′–7″	6	1/2″
8′	7′	11″	3/4″	6″	9′–4″	17′–8″	9	1/2″	11″	1/2″	5″	8′–7″	6	1/2″
8′	8′	11″	3/4″	6″	9′–4″	17′–8″	9	1/2″	11″	5/8″	5 1/2″	9′–7″	7	1/2″
10′	4	14″	3/4″	5″	11′–8″	20′–9″	10	5/8″	13″	1/2″	12″	6′–1″	4	5/8″
10′	5′	14″	3/4″	5″	11′–8″	20′–9″	10	5/8″	13″	1/2″	11″	7′–1″	4	5/8″
10′	6′	14″	3/4″	5″	11′–8″	20′–9″	10	5/8″	13″	1/2″	7 1/2″	8′–1″	6	5/8″
10′	7′	14″	3/4″	5″	11′–8″	20′–9″	10	5/8″	13″	5/8″	9″	9′–1″	6	5/8″
10′	8′	14″	3/4″	5″	11′–8″	20′–9″	10	5/8″	13″	5/8″	7″	10′–1″	7	5/8″
10′	9′	14″	3/4″	5″	11′–8″	20′–9″	10	5/8″	13″	5/8″	5 1/2″	11′–1″	8	5/8″
10′	10′	14″	3/4″	5″	11′–8″	20′–9″	10	5/8″	13″	5/8″	4″	12′–1″	8	5/8″

TABLE OF SLAB THICKNESSES AND REINFORCEMENT FOR CULVERTS.—(*Continued*)

Inside culvert dimensions		Depth of fill over top of culverts — 9 ft. deep												
		Top & bottom slabs							Side slabs					
		Thickness, T	Reinforcement						Thickness, S	Reinforcement				
			Transverse				Longitudinal			Vertical			Longitudinal	
W	H		Size φ	Spacing	Length bars "a"	Length bars "b"	No.	Size φ		Size φ	Spacing	Length bars "c"	No.	Size φ
6′	4′	9″	5/8″	6″	7′–0″	14′–0″	7	1/2″	9″	1/2″	10″	5′–3″	4	1/2″
6′	5′	9″	5/8″	6″	7′–0″	14′–0″	7	1/2″	9″	1/2″	7″	6′–3″	4	1/2″
6′	6′	9″	5/8″	6″	7′–0″	14′–0″	7	1/2″	9″	1/2″	5″	7′–3″	6	1/2″
7′	4′	11″	3/4″	8″	8′–4″	16′–8″	8	1/2″	11″	1/2″	12″	5′–7″	4	1/2″
7′	5′	11″	3/4″	8″	8′–4″	16′–8″	8	1/2″	11″	1/2″	9″	6′–7″	4	1/2″
7′	6′	11″	3/4″	8″	8′–4″	16′–8″	8	1/2″	11″	1/2″	6″	7′–7″	6	1/2″
7′	7′	11″	3/4″	8″	8′–4″	16′–8″	8	1/2″	11″	1/2″	4 1/2″	8′–7″	6	1/2″
8′	4′	12″	3/4″	6 1/2″	9′–6″	18′–1″	9	1/2″	12″	1/2″	12″	5′–9″	4	1/2″
8′	5′	12″	3/4″	6 1/2″	9′–6″	18′–1″	9	1/2″	12″	1/2″	9 1/2″	6′–9″	4	1/2″
8′	6′	12″	3/4″	6 1/2″	9′–6″	18′–1″	9	1/2″	12″	1/2″	7″	7′–9″	6	1/2″
8′	7′	12″	3/4″	6 1/2″	9′–6″	18′–1″	9	1/2″	12″	5/8″	8″	8′–9″	6	1/2″
8′	8′	12″	3/4″	6 1/2″	9′–6″	18′–1″	9	1/2″	12″	5/8″	6″	9′–9″	7	1/2″
10′	4′	15″	7/8″	6 1/2″	11′–10″	21′–11″	10	5/8″	14″	1/2″	12″	6′–3″	4	5/8″
10′	5′	15″	7/8″	6 1/2″	11′–10″	21 –11″	10	5/8″	14″	1/2″	11″	7′–3″	4	5/8″
10′	6′	15″	7/8″	6 1/2″	11′–10″	21′–11″	10	5/8″	14″	1/2″	8″	8′–3″	6	5/8″
10′	7′	15″	7/8″	6 1/2″	11′–10″	21′–11″	10	5/8″	14″	5/8″	9″	9′–3″	6	5/8″
10′	8′	15″	7/8″	6 1/2″	11′–10″	21′–11″	10	5/8″	14″	5/8″	7″	10′–3″	7	5/8″
10′	9′	15″	7/8″	6 1/2″	11′–10″	21′–11″	10	5/8″	14″	5/8″	5 1/2″	11′–3″	8	5/8″
10′	10′	15″	7/8″	6 1/2″	11′–10″	21′–11″	10	5/8″	14″	5/8″	4 1/2″	12′–3″	8	5/8″

FIG. 67.—(*Continued.*)

TABLE OF SLAB THICKNESSES AND REINFORCEMENT FOR CULVERTS.—(*Continued*)

Inside culvert dimensions		Depth of fill over top of culverts — 10 ft. deep												
		Top & bottom slabs							Side slabs					
		Thickness, T	Reinforcement						Thickness, S	Reinforcement				
			Transverse				Longitudinal			Vertical			Longitudinal	
W	H		Size φ	Spacing	Length bars "a"	Length bars "b"	No.	Size φ		Size φ	Spacing	Length bars "c"	No.	Size φ
6′	4′	10″	⅝″	6″	7′–2″	14′–5″	7	½″	10″	½″	11″	5′–5″	4	½″
6′	5′	10″	⅝″	6″	7′–2″	14′–5″	7	½″	10″	½″	7½″	6′–5″	4	½″
6′	6′	10″	⅝″	6″	7′–2″	14′–5″	7	½″	10″	½″	5″	7′–5″	6	½″
7′	4′	11″	¾″	7″	8′–4″	16′–8″	8	½″	11″	½″	12″	5′–7″	4	½″
7′	5′	11″	¾″	7″	8′–4″	16′–8″	8	½″	11″	½″	8″	6′–7″	4	½″
7′	6′	11″	¾″	7″	8′–4″	16′–8″	8	½″	11″	½″	5½″	7′–7″	6	½″
7′	7′	11″	¾″	7″	8′–4″	16′–8″	8	½″	11″	½″	4″	8′–7″	6	½″
8′	4′	12″	¾″	6″	9′–6″	18′–1″	9	½″	12″	½″	12″	5′–9″	4	½″
8′	5′	12″	¾″	6″	9′–6″	18′–1″	9	½″	12″	½″	9″	6′–9″	4	½″
8′	6′	12″	¾″	6″	9′–6″	18′–1″	9	½″	12″	⅝″	10″	7′–9″	6	½″
8′	7′	12″	¾″	6″	9′–6″	18′–1″	9	½″	12″	⅝″	7½″	8′–9″	6	½″
8′	8′	12″	¾″	6″	9′–6″	18′–1″	9	½″	12″	⅝″	5½″	9′–9″	7	½″
10′	4′	15″	⅞″	6½″	11′–10″	21′–11″	10	⅝″	14″	½″	12″	6′–3″	4	⅝″
10′	5′	15″	⅞″	6½″	11′–10″	21′–11″	10	⅝″	14″	½″	10″	7′–3″	4	⅝″
10′	6′	15″	⅞″	6½″	11′–10″	21′–11″	10	⅝″	14″	½″	7″	8′–3″	6	⅝″
10′	7′	15″	⅞″	6½″	11′–10″	21′–11″	10	⅝″	14″	⅝″	8½″	9′–3″	6	⅝″
10′	8′	15″	⅞″	6½″	11′–10″	21′–11″	10	⅝″	14″	⅝″	6½″	10′–3″	7	⅝″
10′	9′	15″	⅞″	6½″	11′–10′	21′–11″	10	⅝″	14″	⅝″	5″	11′–3″	8	⅝″
10′	10′	15″	⅞″	6½″	11′–10″	21′–11″	10	⅝″	14″	⅝″	4″	12′–3″	8	⅝″

FIG. 67.—(*Continued.*)

Inside culvert dimensions		Depth of fill over top of culverts												
		11 ft. deep												
		Top & bottom slabs							Side slabs					
		Thickness, T	Reinforcement						Thickness, S	Reinforcement				
			Transverse				Longitudinal			Vertical			Longitudinal	
W	H		Size ϕ	Spacing	Length bars "a"	Length bars "b"	No.	Size ϕ		Size ϕ	Spacing	Length bars "c"	No.	Size ϕ
6′	4′	10″	5/8″	5 1/2″	7′-2″	14′-5″	7	1/2″	10″	1/2″	10″	5′-5″	4	1/2″
6′	5′	10″	5/8″	5 1/2″	7′-2″	14′-5″	7	1/2″	10″	1/2″	7″	6′-5″	4	1/2″
6′	6′	10″	5/8″	5 1/2″	7′-2″	14′-5″	7	1/2″	10″	1/2″	4 1/2″	7′-5″	6	1/2″
7′	4′	11″	3/4″	6 1/2″	8′-4″	16′-8″	8	1/2″	11″	1/2″	11 1/2″	5′-7″	4	1/2″
7′	5′	11″	3/4″	6 1/2″	8′-4″	16′-8″	8	1/2″	11″	1/2″	7 1/2″	6′-7″	4	1/2″
7′	6′	11″	3/4″	6 1/2″	8′-4″	16′-8″	8	1/2″	11″	1/2″	5 1/2″	7′-7″	6	1/2″
7′	7′	11″	3/4″	6 1/2″	8′-4″	16′-8″	8	1/2″	11″	1/2″	4″	8′-7″	6	1/2″
8′	4′	13″	3/4″	6″	9′-8″	18′-6″	8	5/8″	13″	1/2″	12″	5′-11″	4	5/8″
8′	5′	13″	3/4″	6″	9′-8″	18′-6″	8	5/8″	13″	1/2″	9″	6′-11″	4	5/8″
8′	6′	13″	3/4″	6″	9′-8″	18′-6″	8	5/8″	13″	5/8″	10″	7′-11″	6	5/8″
8′	7′	13″	3/4″	6″	9′-8″	18′-8″	8	5/8″	13″	5/8″	7 1/2″	8′-11″	6	5/8″
8′	8′	13″	3/4″	6″	9′-8″	18′-6″	8	5/8″	13″	5/8″	5 1/2″	9′-11″	7	5/8″
10′	4′	15″	7/8″	6″	11′-10″	21′-11″	10	5/8″	14″	1/2″	12″	6′-3″	4	5/8″
10′	5′	15″	7/8″	6″	11′-10″	21′-11″	10	5/8″	14″	1/2″	9 1/2″	7′-3″	4	5/8″
10′	6′	15″	7/8″	6″	11′-10″	21′-11″	10	5/8″	14″	5/8″	10 1/2″	8′-3″	6	5/8″
10′	7′	15″	7/8″	6″	11′-10″	21′-11″	10	5/8″	14″	5/8″	8″	9′-3″	6	5/8″
10′	8′	15″	7/8″	6″	11′-10″	21′-11″	10	5/8″	14″	5/8″	6″	10′-3″	7	5/8″
10′	9′	15″	7/8″	6″	11′-10″	21′-11″	10	5/8″	14″	5/8″	5″	11′-3″	8	5/8″
10′	10′	15″	7/8″	6″	11′-10″	21′-11″	10	5/8″	14″	5/8″	4″	12′-3″	8	5/8″

FIG. 67.—(*Continued.*)

TABLE OF SLAB THICKNESSES AND REINFORCEMENT FOR CULVERTS.—(*Continued*)

Inside culvert dimensions		Depth of fill over top of culverts												
		12 ft. deep												
		Top & bottom slabs							Side slabs					
		Thickness, T	Reinforcement						Thickness, S	Reinforcement				
			Transverse				Longitudinal			Vertical			Longitudinal	
W	H		Size φ	Spacing	Length bars "a"	Length bars "b"	No.	Size φ		Size φ	Spacing	Length bars "c"	No.	Size φ
6′	4′	10″	¾″	7½″	7′–2″	15′–3″	7	½″	10″	½″	9½″	5′–5″	4	½″
6′	5′	10″	¾″	7½″	7′–2″	15′–3″	7	½″	10″	½″	6½″	6′–5″	4	½″
6′	6′	10″	¾″	7½″	7′–2″	15′–3″	7	½″	10″	½″	4½″	7′–5″	6	½″
7′	4′	12″	¾″	6½″	8′–6″	17′–1″	8	½″	12″	½″	11½″	5′–9″	4	½″
7′	5′	12″	¾″	6½″	8′–6″	17′–1″	8	½″	12″	½″	8″	6′–9″	4	½″
7′	6′	12″	¾″	6½″	8′–6″	17′–1″	8	½″	12″	½″	5½″	7′–9″	6	½″
7′	7′	12″	¾″	6½″	8′–6″	17′–1″	8	½″	12″	½″	4″	8′–9″	6	½″
8′	4′	13″	¾″	5½″	9′–8″	18′–6″	8	⅝″	13″	½″	12″	5′–11″	4	⅝″
8′	5′	13″	¾″	5½″	9 –8″	18′–6″	8	⅝″	13″	½″	8½″	6′–11″	4	⅝″
8′	6′	13″	¾″	5½″	9′–8″	18′–6″	8	⅝″	13″	⅝″	9½″	7′–11″	6	⅝″
8′	7′	13″	¾″	5½″	9′–8″	18′–6″	8	⅝″	13″	⅝″	7″	8′–11″	6	⅝″
8′	8′	13″	¾″	5½″	9′–8″	18′–6″	8	⅝″	13″	⅝″	5½″	9′–11″	7	⅝″
10′	4′	16″	⅞″	6″	12′–0″	22′–4″	10	⅝″	15″	½″	12″	6′–5″	4	⅝″
10′	5′	16″	⅞″	6″	12′–0″	22′–4″	10	⅝″	15″	½″	9½″	7′–5″	4	⅝″
10′	6′	16″	⅞″	6″	12′–0″	22′–4″	10	⅝″	15″	⅝″	10½″	8′–5″	6	⅝″
10′	7′	16″	⅞″	6″	12′–0″	22′–4″	10	⅝″	15″	⅝″	8″	9′–5″	6	⅝″
10′	8′	16″	⅞″	6″	12′–0″	22′–4″	10	⅝″	15″	⅝″	6″	10′–5″	7	⅝″
10′	9′	16″	⅞″	6″	12′–0″	22′–4″	10	⅝″	15″	⅝″	5″	11′–5″	8	⅝″
10′	10′	16″	⅞″	6″	12′–0″	22′–4″	10	⅝″	15″	⅝″	4″	12′–5″	8	⅝″

TABLE OF SLAB THICKNESSES AND REINFORCEMENT FOR CULVERTS.—(*Continued*)

Inside culvert dimensions		Depth of fill over top of culverts												
		13 ft. deep												
		Top & bottom slabs							Side slabs					
		Thick-ness, T	Reinforcement						Thick-ness, S	Reinforcement				
			Transverse			Longitudinal				Vertical			Longitudinal	
W	H		Size φ	Spac-ing	Length bars "a"	Length bars "b"	No.	Size φ		Size φ	Spac-ing	Length bars "c"	No.	Size φ
6′	4′	11″	¾″	7½″	7′-2″	15′-6″	7	½″	10″	½″	9″	5′-7″	4	½″
6′	5′	11″	¾″	7½″	7′-2″	15′-6″	7	½″	10″	½″	6″	6′-7″	4	½″
6′	6′	11″	¾″	7½″	7′-2″	15′-6″	7	½″	10″	½″	4″	7′-7″	6	½″
7′	4′	12″	¾″	6″	8′-6″	17′-1″	8	½″	12″	½″	11″	5′-9″	4	½″
7′	5′	12″	¾″	6″	8′-6″	17′-1″	8	½″	12″	½″	7½″	6′-9″	4	½″
7′	6′	12″	¾″	6″	8′-6″	17′-1″	8	½″	12″	½″	5″	7′-9″	6	½″
7′	7′	12″	¾″	6″	8′-6″	17′-1″	8	½″	12″	½″	4″	8′-9″	6	½″
8′	4′	13″	¾″	5″	9′-8″	18′-6″	8	⅝″	13″	½″	12″	5′-11″	4	⅝″
8′	5′	13″	¾″	5″	9′-8″	18′-6″	8	⅝″	13″	½″	8″	6′-11″	4	⅝″
8′	6′	13″	¾″	5″	9′-8″	18′-6″	8	⅝″	13″	⅝″	9″	7′-11″	6	⅝″
8′	7′	13″	¾″	5″	9′-8″	18′-6″	8	⅝″	13″	⅝″	6½″	8′-11″	6	⅝″
8′	8′	13″	¾″	5″	9′-8″	18′-6″	8	⅝″	13″	⅝″	5″	9′-11″	7	⅝″
10′	4′	16″	1″	7½″	12′-0″	23′-2″	10	⅝″	15″	½″	12″	6′-5″	4	⅝″
10′	5′	16″	1″	7½″	12′-0″	23′-2″	10	⅝″	15″	½″	9″	7′-5″	4	⅝″
10′	6	16″	1″	7½″	12′-0″	23′-2″	10	⅝″	15″	⅝″	10″	8′-5″	6	⅝″
10′	7′	16″	1″	7½″	12′-0″	23′-2″	10	⅝″	15″	⅝″	7½″	9′-5″	6	⅝″
10′	8′	16″	1″	7½″	12′-0″	23′-2″	10	⅝″	15″	¾″	8½″	10′-5″	7	⅝″
10′	9′	16″	1″	7½″	12′-0″	23′-2″	10	⅝″	15″	¾″	6½′	11′-5″	8	⅝″
10′	10′	16″	1″	7½″	12′-0″	23′-2″	10	⅝″	15″	¾″	5½″	12′-5″	8	⅝″

FIG. 67.—(*Continued.*)

TABLE OF SLAB THICKNESSES AND REINFORCEMENT FOR CULVERTS.—(*Continued*)

Inside culvert dimensions		Depth of fill over top of culverts												
		14 ft. deep												
		Top & bottom slabs							Side slabs					
		Thickness, T	Reinforcement						Thickness, S	Reinforcement				
			Transverse				Longitudinal			Vertical			Longitudinal	
W	H		Size φ	Spacing	Length bars "a"	Length bars "b"	No.	Size φ		Size φ	Spacing	Length bars "c"	No.	Size φ
6′	4′	11″	¾″	7″	7′–2″	15′–6″	7	½″	10″	½″	8″	5′–7″	4	½″
6′	5′	11″	¾″	7″	7′–2″	15′–6″	7	½″	10″	½″	5½″	6′–7″	4	½″
6′	6′	11″	¾″	7″	7′–2″	15′–6″	7	½″	10″	½″	4″	7′–7″	6	½″
7′	4′	12″	¾″	6″	8′–6″	17′–1″	8	½″	12″	½″	10″	5′–9″	4	½″
7′	5′	12″	¾″	6″	8′–6″	17′–1″	8	½″	12″	½″	7″	6′–9″	4	½″
7′	6′	12″	¾″	6″	8′–6″	17′–1″	8	½″	12″	½″	5″	7′–9″	6	½″
7′	7′	12″	¾″	6″	8′–6″	17′–1″	8	½″	12″	½″	3½″	8′–9″	6	½″
8′	4′	14″	¾″	5″	9′–8″	18′–9″	8	⅝″	13″	½″	11″	6′–1″	4	⅝″
8′	5′	14″	¾″	5″	9′–8″	18′–9″	8	⅝″	13″	½″	7″	7′–1″	4	⅝″
8′	6′	14″	¾″	5″	9′–8″	18′–9″	8	⅝″	13″	⅝″	8″	8′–1″	6	⅝″
8′	7′	14″	¾″	5″	9′–8″	18′–9″	8	⅝″	13″	⅝″	6″	9′–1″	6	⅝″
8′	8′	14″	¾″	5″	9′–8″	18′–9″	8	⅝″	13″	⅝″	4½″	10′–1″	7	⅝″
10′	4′	17″	1″	7½″	12′–2″	23′–7″	10	⅝″	16″	½″	12″	6′–7″	4	⅝″
10′	5′	17″	1″	7½″	12′–2″	23′–7″	10	⅝″	16″	½″	9″	7′–7″	4	⅝″
10′	6′	17″	1″	7½″	12′–2″	23′–7″	10	⅝″	16″	⅝″	10″	8′–7″	6	⅝″
10′	7′	17″	1″	7⅓″	12′–2″	23′–7″	10	⅝″	16″	⅝″	7½″	9′–7″	6	⅝″
10′	8′	17″	1″	7½″	12′–2″	23′–7″	10	⅝″	16″	¾″	8½″	10′–7″	7	⅝″
10′	9′	17″	1″	7½″	12′–2″	23′–7″	10	⅝″	16″	¾″	6½″	11′–7″	8	⅝″
10′	10′	17″	1″	7½″	12′–2″	23′–7″	10	⅝″	16″	¾″	5½	12′–7″	8	⅝″

FIG. 67.—(*Continued.*)

TABLE OF SLAB THICKNESSES AND REINFORCEMENT FOR CULVERTS.—(*Continued*)

Inside culvert dimensions		Depth of fill over top of culverts												
		15 ft. deep												
		Top & bottom slabs							Side slabs					
		Thickness, T	Reinforcement						Thickness, S	Reinforcement				
			Transverse				Longitudinal			Vertical			Longitudinal	
W	H		Size ϕ	Spacing	Length bars "a"	Length bars "b"	No.	Size ϕ		Size ϕ	Spacing	Length bars "c"	No.	Size ϕ
6′	4′	11″	¾″	6½″	7′-2″	15′-6″	7	½″	10″	½″	8″	5′-7″	4	½″
6′	5′	11″	¾″	6½″	7′-2″	15′-6″	7	½″	10″	½″	5″	6′-7″	4	½″
6′	6′	11″	¾″	6½″	7′-2″	15′-6″	7	½″	10″	½″	3½″	7′-7″	6	½″
7′	4′	13″	¾″	6″	8′-6″	17′-4″	8	½″	12″	½″	9½″	5′-11″	4	½″
7′	5′	13″	¾″	6″	8′-6″	17′-4″	8	½″	12″	½″	6½″	6′-11″	4	½″
7′	6′	13″	¾″	6″	8′-6″	17′-4″	8	½″	12″	½″	4½″	7′-11″	6	½″
7′	7′	13″	¾″	6″	8′-6″	17′-4″	8	½″	12″	½″	3½″	8′-11″	6	½″
8′	4′	14″	¾″	5″	9′-8″	18′-9″	8	⅝″	13″	½″	10″	6′-1″	4	⅝″
8′	5′	14″	¾″	5″	9′-8″	18′-9″	8	⅝″	13″	½″	7″	7′-1″	4	⅝″
8′	6′	14″	¾″	5″	9′-8″	18′-9″	8	⅝″	13″	⅝″	8″	8′-1″	6	⅝″
8′	7′	14″	¾″	5″	9′-8″	18′-9″	8	⅝″	13″	⅝″	6″	9′-1″	6	⅝″
8′	8′	14″	¾″	5″	9′-8″	18′-9″	8	⅝″	13″	⅝″	4½″	10′-1″	7	⅝″
10′	4′	17″	1″	7″	12′-2″	23′-7″	10	⅝″	16″	½″	12″	6′-7″	4	⅝″
10′	5′	17″	1″	7″	12′-2″	23′-7″	10	⅝″	16″	½″	8½″	7′-7″	4	⅝″
10′	6′	17″	1″	7″	12′-2″	23′-7″	10	⅝″	16″	⅝″	9½″	8′-7″	6	⅝″
10′	7′	17″	1″	7″	12′-2″	23′-7″	10	⅝″	16″	⅝″	7″	9′-7″	6	⅝″
10′	8′	17″	1″	7″	12′-2″	23′-7′	10	⅝″	16″	¾″	8″	10′-7″	7	⅝″
10′	9′	17″	1″	7′	12′-2″	23′-7″	10	⅝″	16″	¾″	6½″	11′-7″	8	⅝″
10′	10′	17″	1″	7″	12′-2″	23′-7″	10	⅝″	16″	¾″	5″	12′-7″	8	⅝″

FIG. 67.—(*Continued.*)

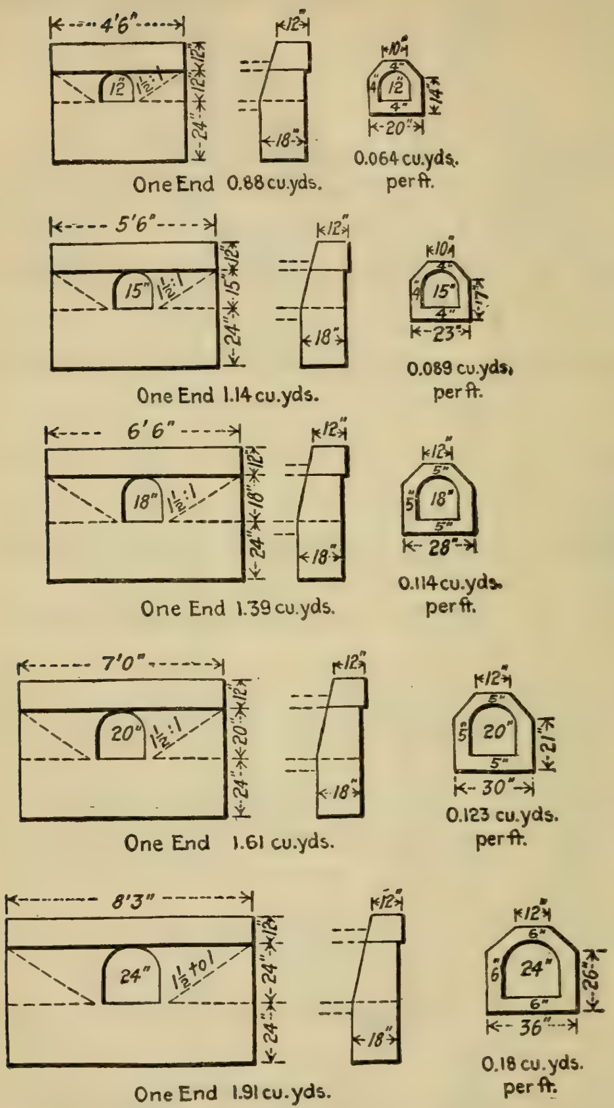


FIG. 68A.—Massachusetts standard for concrete arch culverts.

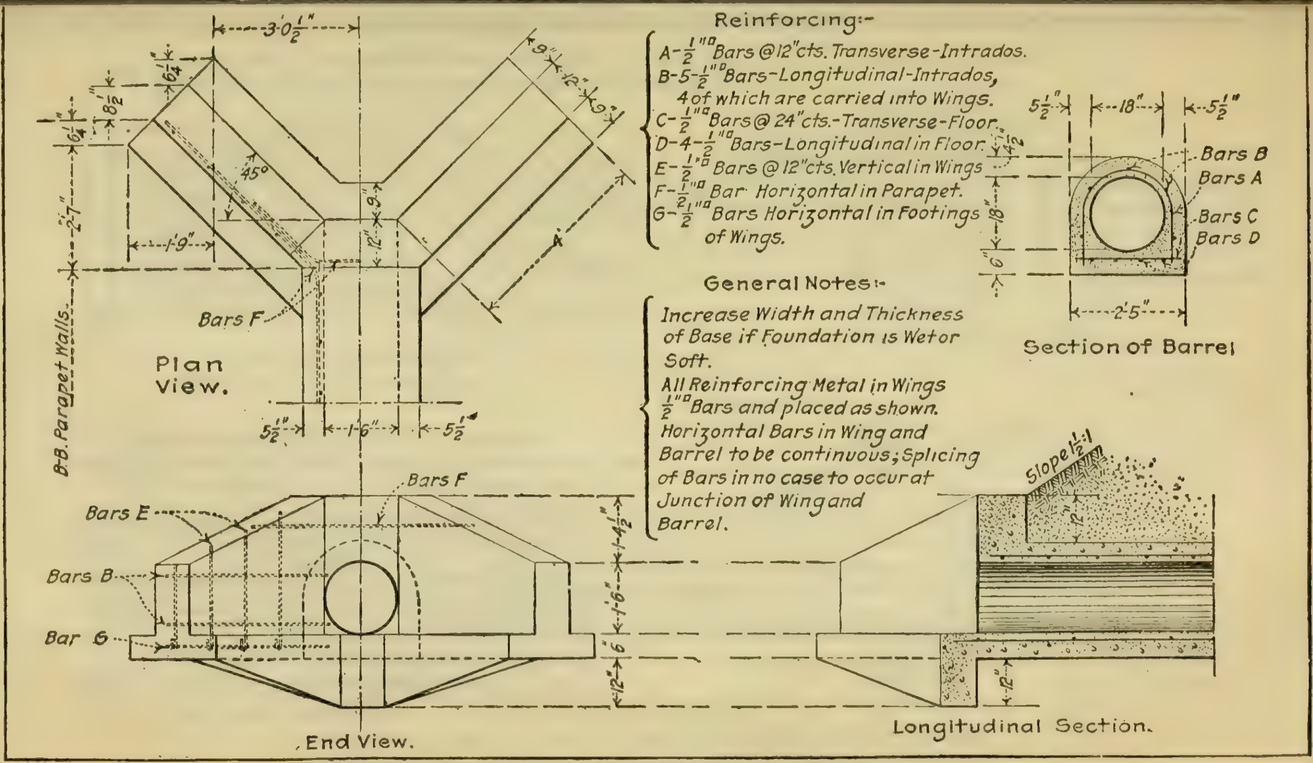


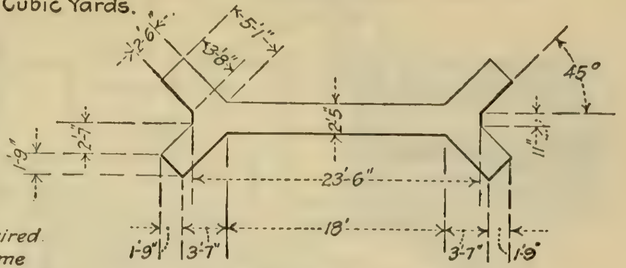
FIG. 68B.—State of Iowa 18″ circular concrete culverts.

18 inch Circular Culvert.
Bill of Reinforcing Steel and Quantities of Concrete Materials
Cubic Contents of Culvert 20 ft. Back to Back of Parapet Walls
Equals, $5\frac{4}{10}$ Cubic Yards.

Concrete Materials.

Item	Quantity Req. for Culvert 20 ft. b.-b. Parapet Walls.	Additional Amount per Ft. Additional Length of Barrel
If Sand and Stone are Used.		
Sand	2.38 Cu. Yds.	0.055 Cu. Yds
Stone	4.80 " "	0.112 " "
Cement	7.9 bbls. or 31.6 Sack	0.182 bbls. or 0.73 Sacks
If Gravel alone is Used.		
Gravel	6.2 Cu. Yds	0.125 Cu. Yds
Cement	10.25 bbls. or 41.0 Sacks	0.238 bbls. or 0.95 Sacks

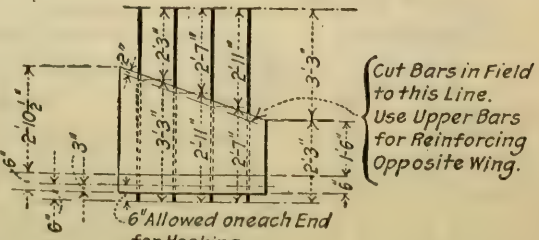
Note { The Table above gives Theoretical Quantities required. To allow for Shrinkage add 20 Per Cent to the Volume of Sand and Stone or Gravel given in Table.



Staking Diagram.

Bill of Reinforcing for Culvert.
20 ft. b-b. Parapet Walls.

Mark	Position	No.	Size	Length	Weight	Remarks
A	Transverse Barrel	22	½" Sq.	4'-10"	90 lb.	
B	Longitud. Barrel	4	"	28'-6"	97 "	Continued into Wings
B	Longitud. Barrel	1	"	21'-6"	18 "	Center Bar
C	Transverse Floor	12	"	2'-3"	23 "	
D	Longitud. Floor	4	"	23'-0"	78 "	Cut in Field per Sketch
E	Vertical Wings	8	"	5'-6"	38 "	Continued into Wings
F	Horizont. Parapet	2	"	5'-6"	9 "	
G	Horizont. Footings	4	"	4'-0"	14 "	
Total Reinforcing Steel 367 lb.						



Elevation of Wing.

Note: { For each additional Foot of Barrel use one additional Bar "A", One Half Bar "C", increase Length of Bars "B" and "D" by One Foot.

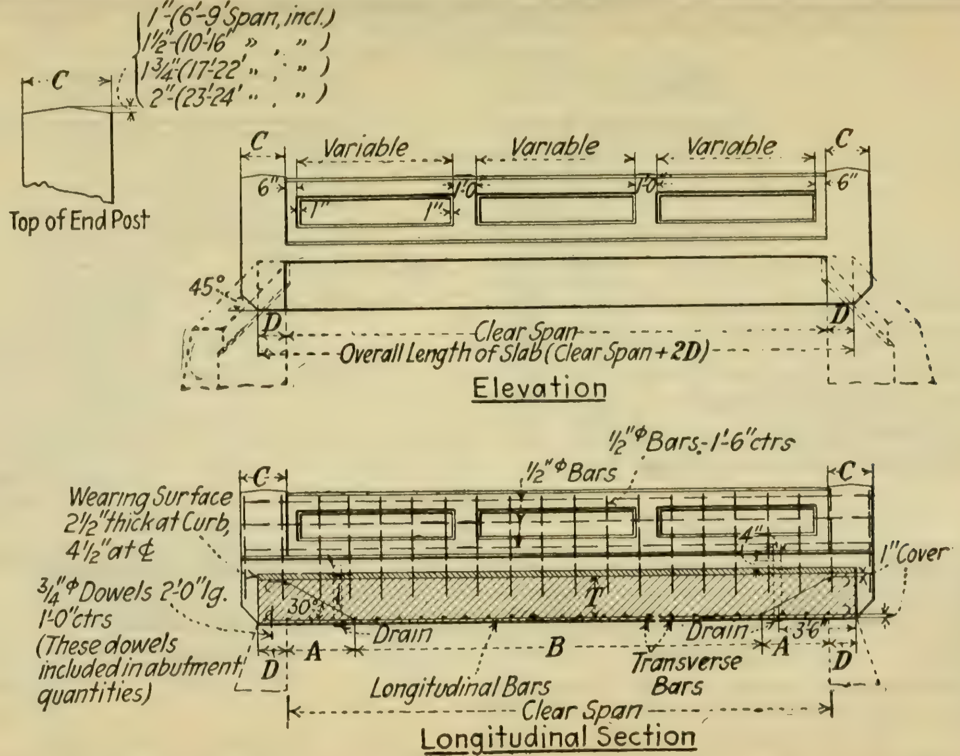


FIG. 69A.—Slab bridge superstructures (H-20 loading) (6 to 25 clear spans). New York State Standards 1926. Dimensions and bar lists see pages 239 and 240.

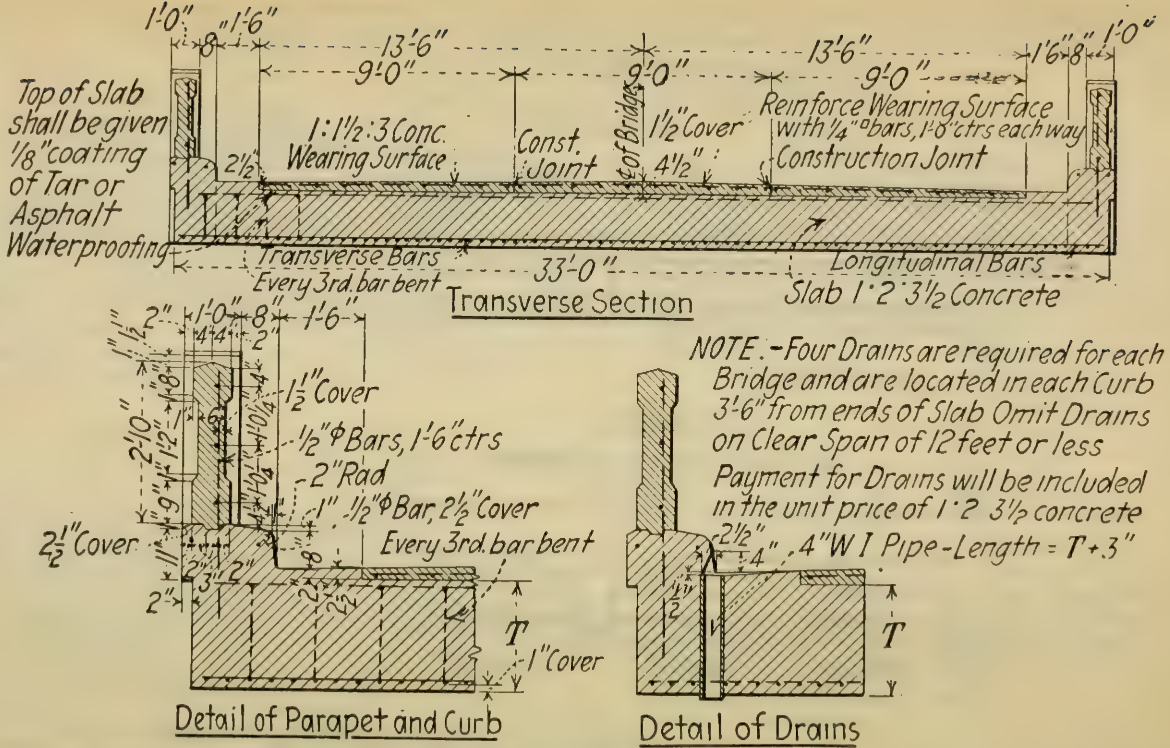


Fig. 69A.—(*Continued.*)

Note.—In 1927 pavement wearing surface has been increased in depth to 6" at middle and 4" at edges.

Dimensions						Slab									
						Longitudinal bars						Transverse bars			
Clear span	A	B	C	D	T	Size	C. to C.	No straight	Length	No bent	Length	Size	C. to C.	No.	Length
6	1'-0"	4'-0"	1'-0"	1'-0"	10"	½" □	4"	66	8'-2"	33	8'-5"	½" φ	1'-0"	11	32'-9"
7	1'-1"	4'-10"	1'-0"	1'-0"	10½"	⅝" φ	4½"	59	9'-4"	29	9'-7"	½" φ	1'-0"	12	32'-9"
8	1'-3"	5'-6"	1'-0"	1'-0"	11½"	⅝" φ	4"	66	10'-4"	33	10'-8"	½" φ	1'-0"	13	32'-9"
9	1'-4"	6'-4"	1'-0"	1'-0"	12"	¾" φ	5¼"	50	11'-6"	25	11'-10"	½" φ	1'-0"	14	32'-9"
10	1'-5"	7'-2"	1'-6"	1'-0"	12½"	¾" φ	5"	52	12'-6"	26	12'-10"	½" φ	1'-0"	15	32'-9"
11	1'-6"	8'-0"	1'-6"	1'-0"	13½"	¾" φ	4½"	59	13'-6"	29	13'-11"	½" φ	1'-0"	16	32'-9"
12	1'-8"	8'-8"	1'-6"	1'-3"	14½"	¾" φ	4¼"	62	15'-0"	31	15'-5"	½" φ	1'-0"	17	32'-9"
13	1'-9"	9'-6"	1'-6"	1'-3"	15"	¾" φ	4"	66	16'-0"	33	16'-6"	½" φ	1'-0"	18	32'-9"
14	1'-10"	10'-4"	1'-6"	1'-3"	15½"	¾" φ	4"	66	17'-0"	33	17'-6"	½" φ	1'-0"	19	32'-9"
15	1'-11"	11'-2"	1'-6"	1'-3"	16½"	⅞" φ	5¼"	50	18'-0"	25	18'-6"	½" φ	1'-0"	20	32'-9"
16	2'-0"	12'-0"	1'-6"	1'-3"	17"	⅞" φ	5"	52	19'-0"	26	19'-7"	½" φ	1'-0"	21	32'-9"
17	2'-2"	12'-8"	1'-9"	1'-3"	18"	⅞" φ	4¾"	55	20'-0"	28	20'-7"	½" φ	1'-0"	22	32'-9"
18	2'-4"	13'-4"	1'-9"	1'-6"	19"	⅞" φ	4½"	59	21'-6"	29	22'-2"	½" φ	1'-0"	23	32'-9"
19	2'-5"	14'-2"	1'-9"	1'-6"	19½"	⅞" φ	4¼"	62	22'-6"	31	23'-2"	½" φ	1'-0"	24	32'-9"
20	2'-6"	15'-0"	1'-9"	1'-6"	20½"	⅞" φ	4"	66	23'-6"	33	24'-3"	½" φ	1'-0"	25	32'-9"
21	2'-7"	15'-10"	1'-9"	1'-6"	21"	1" φ	5¼"	50	24'-8"	25	25'-5"	½" φ	1'-0"	26	32'-9"
22	2'-8"	16'-8"	1'-9"	1'-6"	21½"	1" φ	5"	52	25'-8"	26	26'-5"	½" φ	1'-0"	27	32'-9"
23	2'-10"	17'-4"	2'-0"	1'-6"	22½"	1" φ	4¾"	55	26'-8"	28	27'-6"	½" φ	1'-0"	28	32'-9"
24	2'-11'	18'-2"	2'-0"	1'-6"	23½"	1" φ	4½"	62	27'-8"	31	28'-6"	½" φ	1'-0"	29	32'-9"

FIG. 69A.—(*Continued.*)

Span	Parapet and curb						Wearing surface						Quantities				
	Longitudinal bars			Vertical bars			Longitudinal bars			Transverse bars			1–2–3½ concrete	1–1½–3 concrete	Cement	Waterproofing	Reinforcing bars
	No.	Size	Length	No.	Size	Length	No.	Size	Length	No.	Size	Length	Cu. yds.	Cu. yds.	Bbls.	Sq. ft.	Lbs.
6	10	½″φ	7′–8″	16	½″φ	4′–2″	30	¼″□	7′–8″	27	¼″□	8′–8″	9.2	3.6	22¾	219	1130
7	10	½″φ	8′–8″	18	½″φ	4′–2″	30	¼″□	8′–8″	30	¼″□	8′–8″	10.7	4.0	26¼	247	1340
8	10	½″φ	9′–8″	20	½″φ	4′–4″	30	¼″□	9′–8″	33	¼″□	8′–8″	13.0	4.4	31.0	274	1600
9	10	½″φ	10′–8″	20	½″φ	4′–4″	30	¼″□	10′–8″	36	¼″□	8′–8″	14.9	4.8	35.0	302	1880
10	10	½″φ	12′–8″	22	½″φ	4′–4″	30	¼″□	11′–8″	39	¼″□	8′–8″	17.0	5.4	39¾	329	2100
11	10	½″φ	13′–8″	24	½″φ	4′–4″	30	¼″□	12′–8″	42	¼″□	8′–8″	19.7	5.9	45¼	356	2470
12	10	½″φ	14′–8″	24	½″φ	4′–4″	30	¼″□	14′–2″	45	¼″□	8′–8″	23.5	6.5	53.0	398	2820
13	10	½″φ	15′–8″	26	½″φ	4′–4″	30	¼″□	15′–2″	48	¼″□	8′–8″	25.8	6.9	57¾	425	3160
14	10	½″φ	16′–8″	28	½″φ	4′–4″	60	¼″□	8′–6″	51	¼″□	8′–8″	28.3	7.3	62¾	452	3360
15	10	½″φ	17′–8″	28	½″φ	4′–4″	60	¼″□	9′–0″	54	¼″□	8′–8″	31.7	7.7	69½	480	3640
16	10	½″φ	18′–8″	30	½″φ	4′–4″	60	¼″□	9′–6″	57	¼″□	8′–8″	34.7	8.1	75¼	507	3960
17	10	½″φ	20′–2″	32	½″φ	4′–4″	60	¼″□	10′–0″	60	¼″□	8′–8″	38.6	8.6	82¾	535	4370
18	10	½″φ	21′–2″	32	½″φ	4′–4″	60	¼″□	10′–9″	63	¼″□	8′–8″	43.4	9.2	92¼	576	4900
19	10	½″φ	22′–2″	34	½″φ	4′–4″	60	¼″□	11′–3″	66	¼″□	8′–8″	46.6	9.6	98¼	603	5360
20	10	½″φ	23′–2″	36	½″φ	4′–4″	60	¼″□	11′–9″	69	¼″□	8′–8″	51.2	10.0	107.0	631	5890
21	10	½″φ	24′–2″	36	½″φ	4′–4″	60	¼″□	12′–3″	72	¼″□	8′–8″	54.6	10.4	113¾	658	6110
22	10	½″φ	25′–2″	38	½″φ	4′–4″	60	¼″□	12′–9″	75	¼″□	8′–8″	58.1	10.9	120¾	686	6570
23	10	½″φ	26′–8″	40	½″φ	4′–4″	60	¼″□	13′–3″	78	¼″□	8′–8″	63.1	11.4	130	713	7190
24	10	½″φ	27′–8″	40	½″φ	4′–4″	60	¼″□	13′–9″	81	¼″□	8′–8″	68.5	11.8	140	740	8200

Camber bridge ¹⁄₁₆″ per foot of clear span. Reinforcing bars may be spliced at places approved by the Engineer. Bars so spliced shall be lapped 40 diameters.

Concrete in slab and curb shall be nominal mix 1–2–3½. (2200 lbs. per sq. in.)

Concrete in parapet and concrete pavement shall be nominal mix 1–1½–3. (2500 lbs. per sq. in.)

Curbs and slab shall be poured at the same time, allowing no time for initial set to take place between them.

All reinforcing bars shall be medium, open hearth steel. Dimensions for bending reinforcing bars are measured from centers of bars. When reinforcing bars are hooked at end, the radius of the hook shall be 3 times the diameter of bar.

Parapet, fascia and curb surfaces shall be given a rubbed finish, cost to be included in unit price of 1–1½–3 concrete.

For name plate see sheet and the specifications.

Bridges of 12′–0″ clear span or less shall have one panel only on each face of parapet.

For details of abutments see page 241.

FIG. 69A.—(*Continued.*)

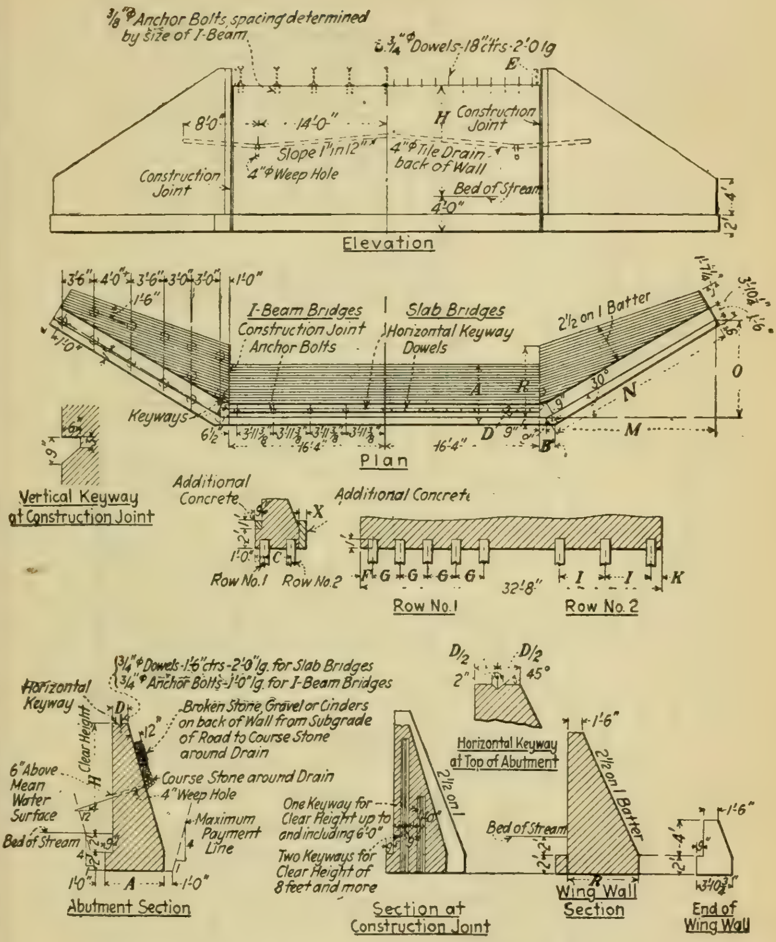


FIG. 69*B*.—Standard abutments slab bridges. New York State 1926.

(Dimensions and Quantities pages 242–245.)

NOTE.—Designed for ordinary soils. If gravel, hardpan or rock foundation occurs, wing back batters can be reduced.

Slab bridges												
Abutment						Wing walls						
Clear span ft.	Clear height, H ft.	A	D	Cu. yds. conc. 1-abut.	Toe pres. tons	B	E	M	N	O	R	Cu. yds. conc. 2 wings
6 to 11	2	2′–9″	1′–0″	13.9	1.3	11″	10½″	1′–11½″	2′– 3″	1′– 1½″	3′– 5½″	3.8
	4	3′–3″		20.6	1.5	1′–2 ″		4′–11½″	5′– 8¾″	2′–10¼″	4′– 3¼″	10.7
	6	4′–0″		30.3	1.6	1′– 5″		7′–11½″	9′– 2″	4′– 7¼″	5′– 1″	20.1
	8	5′–0″		43.9	1.8	1′– 8″		10′–11½″	12′– 7¾″	6′– 4″	5′–10¾″	32.4
12 to 17	4	3′–3″	1′–3″	21.5	1.7	1′– 2″	1′– 3½″	5′– 7″	6′– 5½″	3′– 2¾″	4′– 5½″	12.2
	6	4′–0″		31.5	1.8	1′– 5″		8′– 7″	9′–11″	4′–11½″	5′– 3¼″	22.1
	8	4′–9″		43.3	2.0	1′– 8″		11′– 7″	13′– 4½″	6′– 8″	6′– 1″	35.1
	10	5′–6″		56.9	2.1	1′–11″		14′– 7″	16′–10″	8′– 4¾″	6′–10¾″	51.3
18 to 24	4	3′–3″	1′–6″	22.4	1.9	1′– 2″	1′–10½″	6′– 5½″	7′– 5¼″	3′– 8¾″	4′– 8″	14.2
	6	4′–0″		32.7	2.2	1′– 5″		9′– 5½″	10′–10¾″	5′– 5½″	5′– 6″	24.8
	8	4′–9″		44.8	2.4	1′– 8″		12′– 5½″	14′– 4¼″	7′– 2″	6′– 3½″	38.4
	10	5′–7″		59.5	2.5	1′–11″		15′– 5½″	17′– 9¾″	8′–11″	7′– 1½″	55.6
	12	6 –5″		76.3	2.5	2′– 2″		18′– 5½″	21′– 3½″	10′– 7¾″	7′–11¼″	76.5

FIG. 69*B*.—(*Continued.*)

Clear span, ft.	Clear height, ft.	Slab and I beam bridges								
		Abutment—pile foundation								
		C	Row No. 1		Row No. 2		No. piles required		Abutment footing	
			F	G	K	I			X	Additional concrete
6 to 11	2	Use box culvert, if soil bearing is too low.								Cu. yds.
	4	2′–0″	1′–4″	5′–0″	1′–4″	5′–0″	14	Staggered	9″	3.7
	6	2′–6″	1′–2″	4′–4″	3′–0″	6′–8″	13		6″	2.9
	8	2′–9″	1′–2″	4′–4″	1′–4″	6′–0″	14		0″	0.9
12 to 17	4	2′–0″	1′–4″	5′–0″	1′–4″	5′–0″	14	Staggered	9″	3.7
	6	2′–6″	1′–4″	3′–9″	3′–0″	6′–8″	14		6″	2.9
	8	2′–9″	1′–4″	3′–9″	1′–4″	6′–0″	15		0″	0.9
	10	3′–0″	1′–4″	3′–4″	1′–2″	4′–4″	18		0″	0.9
18 to 24	4	2′–0″	1′–4″	3′–4″	3′–0″	6′–8″	15	Staggered	9″	3.7
	6	2′–6″	1′–4″	3′–4″	3′–0″	6′–8″	15	Staggered	6″	2.9
	8	2′–9″	1′–4″	3′–0″	1′–4″	5′–0″	18		0″	0.9
	10	3′–0″	1′–4″	3′–0″	1′–4″	3′–9″	20		0″	0.9
	12	3′–6″	1′–4″	3′–0″	1′–4″	3′–0″	22		0″	0.9

NOTE: Estimated length of piles 20′.

FIG. 69B.—(*Continued.*)

Abutment—I beam bridges					Wing walls for I beam bridges—spans 10 to 24 incl.								
Clear span	Clear height, H	A	D	Cu. yds. conc. 1-abut	Clear span	Clear height, H	B	E	M	N	O	R	Cu. yds. conc. 2 wings
10′ to 24′	2′	2′–9″	1′–6″	14.5	10′ to 13′ incl. (12″ & 15″ beams)	2′	11″	1′–9″	3′– 3¼″	3′– 9¼″	1′–10¾″	3′– 9¾″	6.0
	4′	3′–3″	1′–6″	22.4		4′	1′– 2″	1′–9″	6′– 3¼″	7′– 3″	3′– 7½″	4′– 7¾″	13.6
	6′	4′–0″	1′–6″	32.7		6′	1′– 5″	1′–9″	9′– 3¼″	10′– 8½″	5′– 4¼″	5′– 5½″	23.9
	8′	4′–9″	1′–6″	44.8		8′	1′– 8″	1′–9″	12′– 3¼″	14′– 1¾″	7′– 1″	6′– 3¼″	37.3
	10′	5′–7″	1′–6″	59.5	14′ to 18′ incl. and 23′ (18″ beam)	4′	1′– 2″	2′–0″	6′– 7¾″	7′– 8″	3′–10″	4′– 9″	14.7
	12′	6 –5″	1′–6″	76.3		6′	1′– 5″	2′–0″	9′– 7¾″	11′– 1½″	5′– 6¾″	5′– 6¾″	25.5
						8′	1′– 8″	2′–0″	12′– 7¾″	14′– 7¼″	7′– 3½″	6′– 4½″	39.4
						10′	1′–11″	2′–0″	15′– 7¾″	18′– 1″	9′– 0½″	7′– 2¼″	56.3
					19′ to 22′ incl. and 24′ (20″ beam)	4′	1′– 2″	2′–2″	6′–10¾″	7′–11½″	3′–11¾″	4′– 9¾″	15.5
						6′	1′– 5″	2′–2″	9′–10¾″	11′– 5″	5′– 8¾″	5′– 7½″	26.5
						8′	1′– 8″	2′–2″	12′–10¾″	14′–10¾″	7′– 5½″	6′– 5¼″	40.5
						10′	1′–11″	2′–2″	15′–10¾″	18′– 4¼″	9′– 2¼″	7′– 3″	58.0
						12′	2′– 2″	2′–2″	18′–10¾″	21′– 9½″	10′–11″	8′– 0¾″	82.1
					23′ and 24′ (24″ beam)	4′	1′– 2″	2′–6″	7′– 4¾″	8′– 6½″	4′– 3¼″	4′–11¼″	17.1
						6′	1′– 5″	2′–6″	10′– 4¾″	12′– 0″	6′– 0″	5′– 9″	28.5
						8′	1′– 8″	2′–6″	13′– 4¾″	15′– 5¾″	7′– 9″	6′– 6¾″	41.6
						10′	1′–11″	2′–6″	16′– 4¾″	18′–11″	9′– 5½″	7′– 4¾″	61.2
						12′	2′– 2″	2′–6″	19′– 4¾″	22′– 4¾″	11′– 2½″	8′– 2½″	83.3

FIG. 69*B*.—I beam bridge abutments 13′ to 25′ spans.—(*Continued.*)

The abutments and wing walls shown on this drawing are typical only. The Engineer will give definite elevations and dimensions for each bridge.

The depth of footings shall be determined with respect to the character of the foundation material and the possibility of undermining—all footings shall rest on a firm foundation and except where rock is encountered, shall be at a depth at least four feet below the bed of stream or surface of ground.

The wing walls shall be designed and detailed to suit existing conditions and the angle between abutment and wing wall and the relative elevations of footings, shall be made to fit the ground. In case it appears that the soil will not safely withstand the unit pressure noted in the above table of abutment dimensions, timber piles shall be used and spaced as shown in the table. The piles are designed for a maximum load of 15 tons per pile. The tops of piles shall be placed below low water elevation. In case excessive erosive action of the stream is expected, piles shall be used rip rap placed in front of the abutment or other approved means taken to prevent erosion.

Concrete in abutments and wing walls shall be 1 : 2½ : 5 Mix, Item No. 21.

Keyways between abutments and wing walls and at all horizontal joints, shall comprise about 30 % of the area of surface.

All exposed edges of concrete shall be chamfered 1 inch.

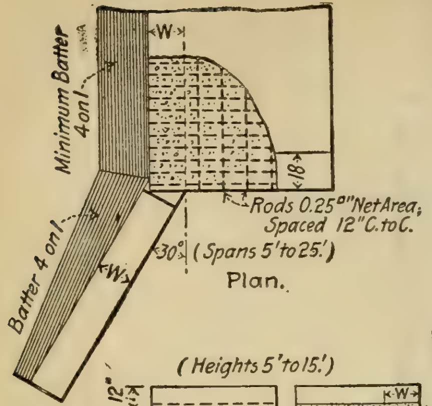
The bases of structures shown on this sheet shall be considered as approximate only and may be ordered in writing by the Engineer to be at any elevation and of any dimensions, necessary to give a proper foundation.

Payment for furnishing and placing dowels, expansion plates and bolts will be made at the respective contract prices for Metal Reinforcement and Structural Steel. (See superstructure details.)

Cost of furnishing and placing material for 4″ tile drain on the back of abutments will be paid for under Item No. 7.

Porous material placed on back of wall will be paid for as excavation.

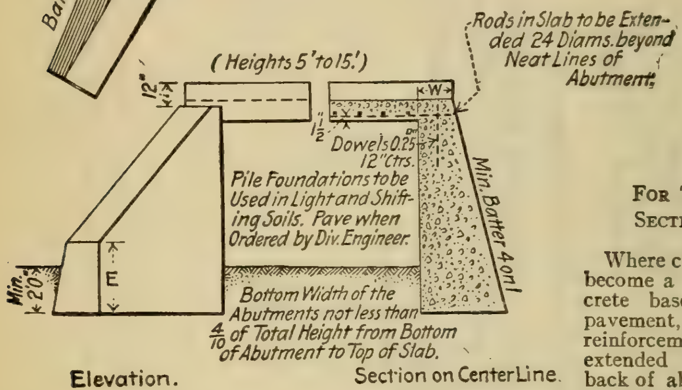
FIG. 69*B*.—(*Continued.*)



Note

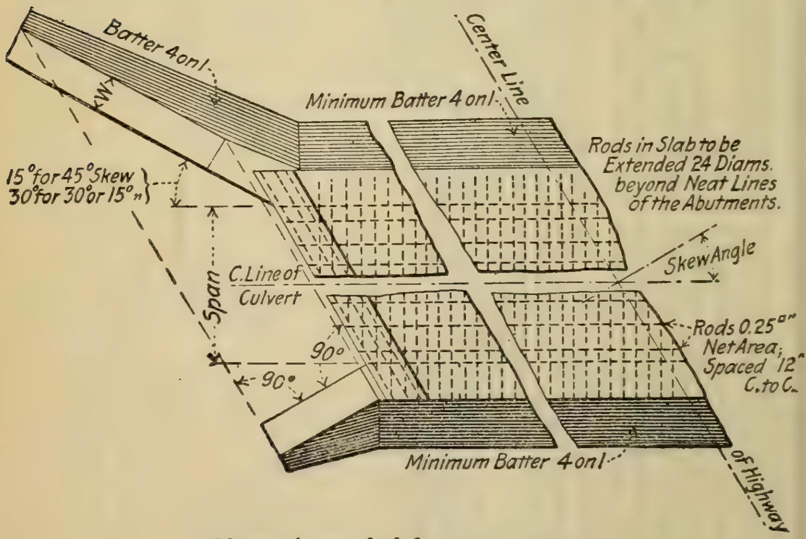
All rods to have a deformed cross-section. All rib metal to be of medium steel.

2d class concrete in all slabs and parapets. 3d class concrete in wings invert and abutments. Wing walls on the outlet end of all square culverts with concrete floors to be built parallel to the center line of the culvert. Round all exposed edges to 1½ inch radius.



For Typical Section "F"

Where culvert covers become a part of concrete base for brick pavement, transverse reinforcement should be extended 12" beyond back of abutment into concrete base.



Dimensions of slabs on page 247.

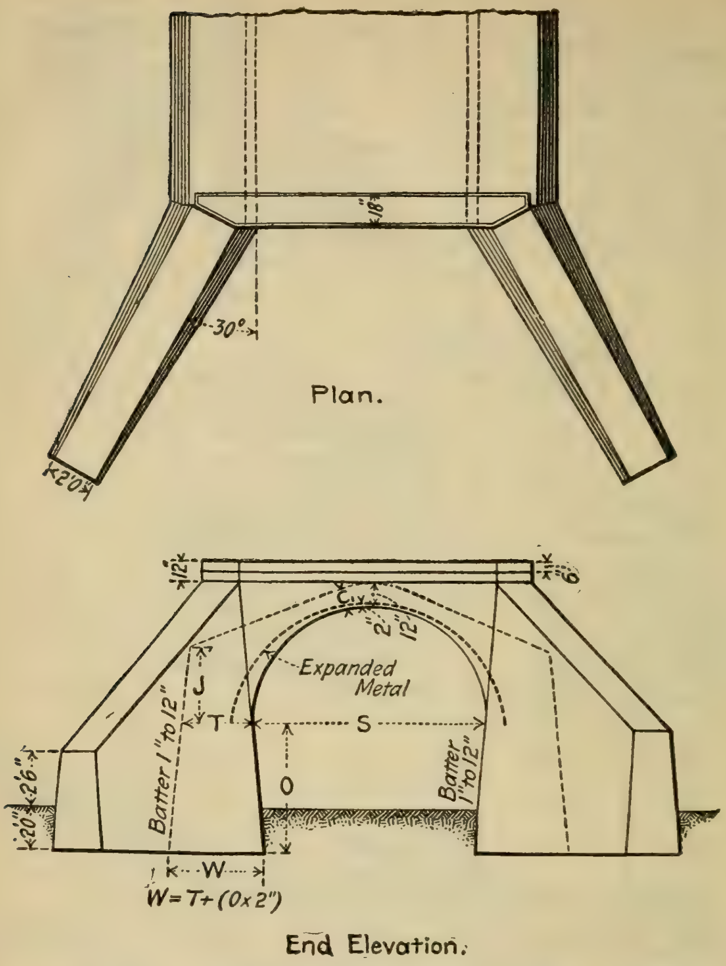
FIG. 70.—New York State slab bridges. **H-15 loading.**

Span	Thickness of Slab*	Net Area of Rods	Rod Spacing C–C	Length of Dowels
5	8″	0.25sq.″	4½″	12″
6	9″	"	4″	"
7	10″	0.39sq.″	5¾″	"
8	10″	"	5¼″	"
9	11″	"	5″	"
10	12″	"	4¾″	"
11	12″	0.56sq.″	6¼″	"
12	13″	"	6″	18″
13	13″	"	5¾″	"
14	14″	"	5⅜″	"
15	14″	"	5″	"
16	15″	"	4¾″	"
17	15″	"	4¾″	"
18	16″	"	4½″	"
19	17″	"	4¼″	"
20	18″	0.77sq.″	5¼″	"
21	18″	"	5¼″	"
22	19″	"	5″	24″
23	19″	"	5″	"
24	20″	"	4⅝″	"
25	21″	1.00sq.″	5⅞″	"

For Spans 5′ to 19′ W = 18″ For Clear Height 10′ or less
" " 5′ to 19′ W = 24″ " " " 11′ to 15′
" " 20′ to 25′ W = 24″ " " " 15′ or less
For Clear Height 7′ or less E = 3′-0″
" " " 8′ to 10′ E = 4′-0″
" " " above 10′ E = 5′-0″

* NOTE.—The thickness of slab given is for shallow fills. For he effect of deep fills see Table 193, page 1075.

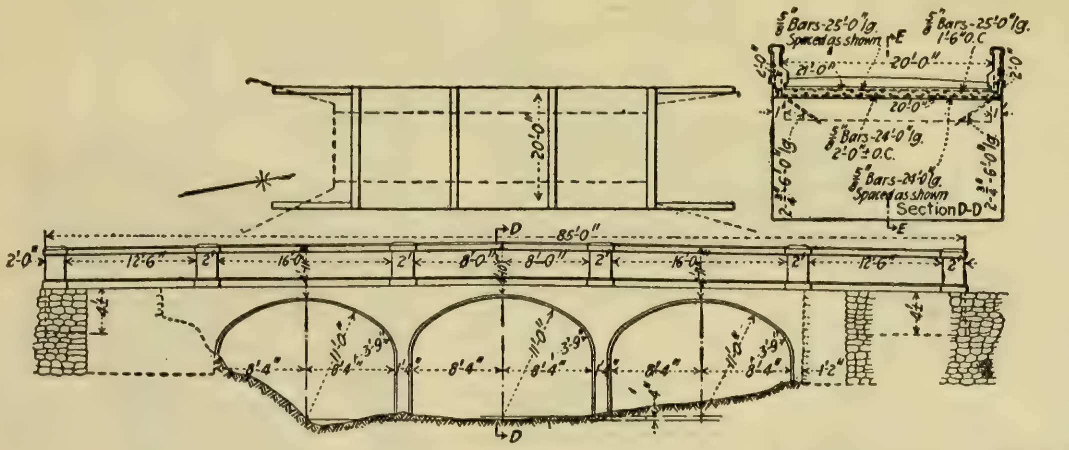
FIG. 70.—(*Continued.*)



GENERAL DIMENSIONS SEMI-CIRCULAR ARCH CULVERTS

S Span	Thickness at Springing Line		Thickness of Ring		Height of Haunch	
	T Concrete	K Masonry	C Concrete	R Masonry	J Concrete	V Masonry
6	2'-6"	2'-6"	10"	10"	1'-9"	2'-0"
8	2'-6"	2'-6"	11"	12"	2'-6"	2'-6"
10	3'-0"	3'-0"	12"	12"	3'-0"	3'-0"
12	3'-6"	3'-6"	14"	15"	3'-6"	3'-9"
14	3'-9"	3'-9"	15"	15"	4'-0"	4'-6"
16	4'-0"	4'-0"	16"	15"	4'-8"	5'-0"
18	4'-6"	4'-6"	18"	18"	5'-0"	5'-6"
20	5'-0"	5'-0"	18"	18"	5'-6"	6'-0"

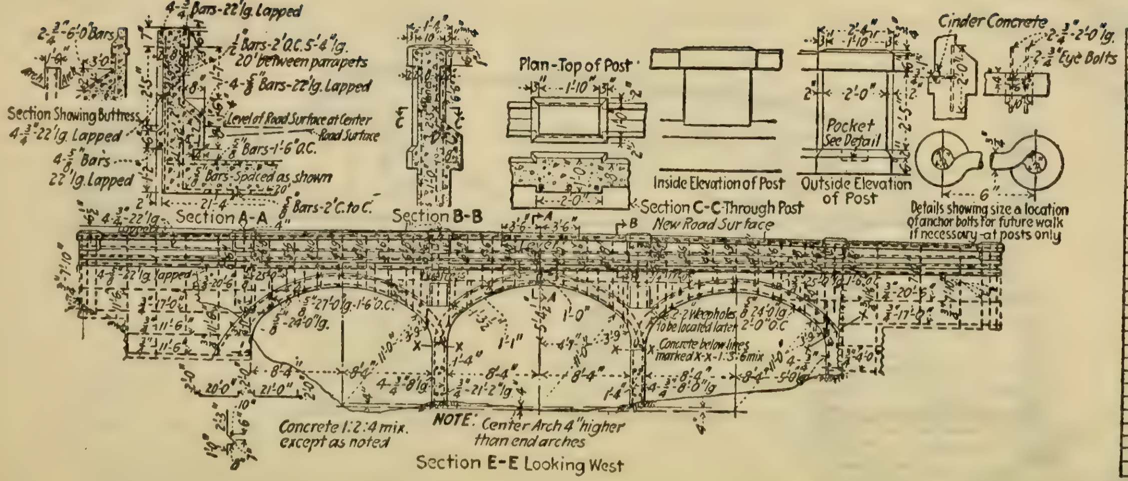
FIG. 71.



STEEL LIST

Number Used	Size	Length	Position	Location
36	5/8	24'-0"	Concentric with Arch	Inside Arch
30	"	25'-0"	"	Outside Arch
15	"	27'-0"	"	" " N.
24	"	24'-0"	Hor.	Inside Arch
18	"	25'-0"	"	Outside Arch
8	3/4	7'-10"	Ver.	Inside End Posts
6	"	11'-6"	"	" Post
20	"	6'-6"	"	" "
16	"	11'-6"	"	Outside Wall
12	"	6'-8"	"	" "
12	"	5'-6"	"	" "
12	"	4'-10"	"	" "
6	"	4'-9"	"	" "
84	1/2	5'-4"	"	Inside Parapet
16	3/4	22'-0"	Hor.	Top of Parapet
8	3/4	22'-0"	"	Outside "
8	5/8	22'-0"	"	Wheel Guard
8	5/8	22'-0"	"	Outside Parapet
4	3/4	20'-6"	"	" Wall
8	"	17'-0"	"	" "
2	"	11'-6"	"	" "
2	"	4'-0"	"	" "
4	"	5'-0"	Ver.	Abutment
16	"	8'-0"	"	Piers
12	"	21'-2"	Hor.	Piers & Abut's.
8	"	6'-0"	Inclined	Buttresses
24	"	2'-0"	Ver.	Posts
24	"	See Detail	Hor.	Posts, 6" c. to c.
4	"	15'-0"	"	Walls, West

FIG. 71A.—Typical multiple span. Reinforced concrete arch.

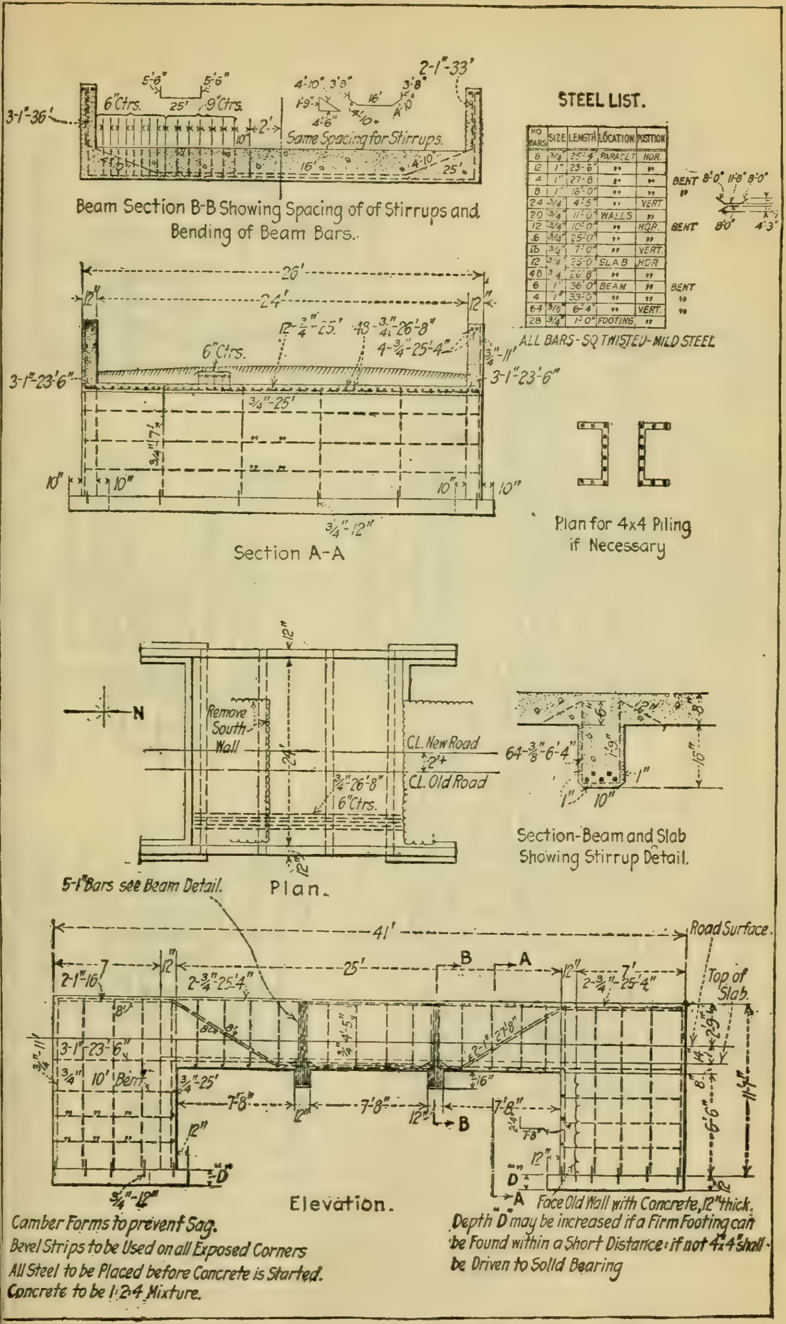


SUMMARY-STEEL TO BE ORDERED

No. of Bars	Size	Length	Total
8	3/4"	7'-10"	62'-8"
6	"	11'-6"	69'-0"
20	"	6'-6"	130'-0"
16	"	11'-6"	184'-0"
12	"	6'-8"	80'-0"
12	"	5'-6"	66'-0"
12	"	4'-10"	58'-0"
6	"	4'-9"	28'-6"
16	"	22'-0"	352'-0"
8	"	22'-0"	176'-0"
4	"	20'-6"	82'-0"
8	"	17'-0"	136'-0"
2	"	11'-6"	23'-0"
2	"	4'-0"	8'-0"
4	"	5'-0"	20'-0"
16	"	8'-0"	128'-0"
12	"	21'-2"	254'-0"
8	"	6'-0"	48'-0"
24	"	2'-0"	48'-0"
4	"	15'-0"	60'-0"
	Total = 2013'-2"	2013 × 1.91 = 3844 Lbs.	
36	5/8"	24'-0"	864'-0"
30	"	25'-0"	750'-0"
15	"	27'-0"	405'-0"
24	"	24'-0"	576'-0"
18	"	25'-0"	450'-0"
8	"	22'-0"	176'-0"
8	"	22'-0"	176'-0"
	Total: 3397'-0"	3397 × 1.33 = 4518 Lbs.	
84	1/2"	5'-4"	448'-0"
			448 × 0.85 = 381 Lbs.
			Total 8743 Lbs.

All bars square twisted mild steel

FIG. 71A.—(*Continued.*)



STEEL LIST.

NO BARS	SIZE	LENGTH	LOCATION	POSITION	
8	3/4"	25'-4"	PARAPET	HOR.	
12	1"	29'-6"	"	"	
4	1"	27'-8"	"	"	BENT 8'-0" 11'-8" 8'-0"
8	1"	16'-0"	"	"	"
24	3/4"	4'-5"	"	VERT	
20	3/4"	11'-0"	WALLS	"	
12	3/4"	10'-0"	"	HOR.	BENT 8'-0" 4'-3"
6	3/4"	25'-0"	"	"	
16	3/4"	7'-0"	"	VERT.	
12	3/4"	25'-0"	SLAB	HOR	
48	3/4"	26'-8"	"	"	
6	1"	36'-0"	BEAM	"	BENT
4	1"	33'-0"	"	"	"
64	3/8"	6'-4"	"	VERT.	"
28	3/4"	1'-0"	FOOTING	"	

ALL BARS-SQ TWISTED-MILD STEEL

Design used by Monroe County, New York State.
FIG. 72.—Parapet girder bridge.

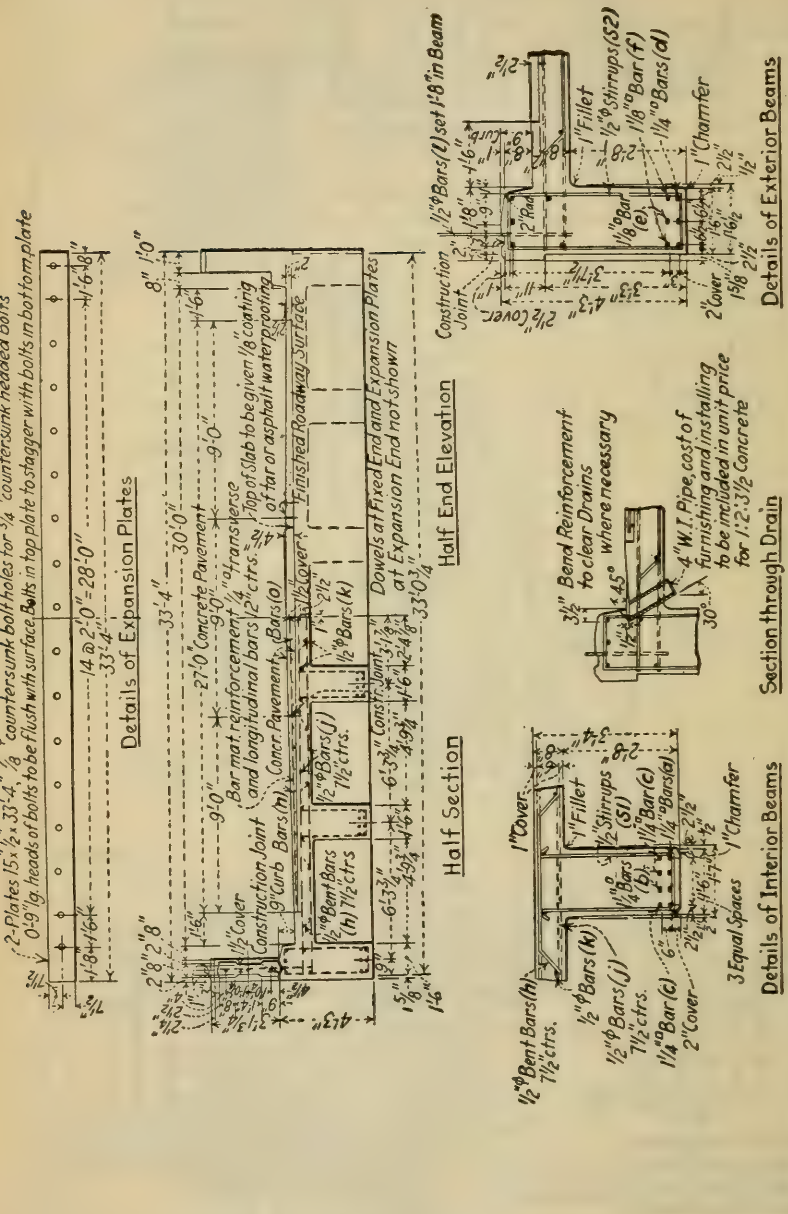
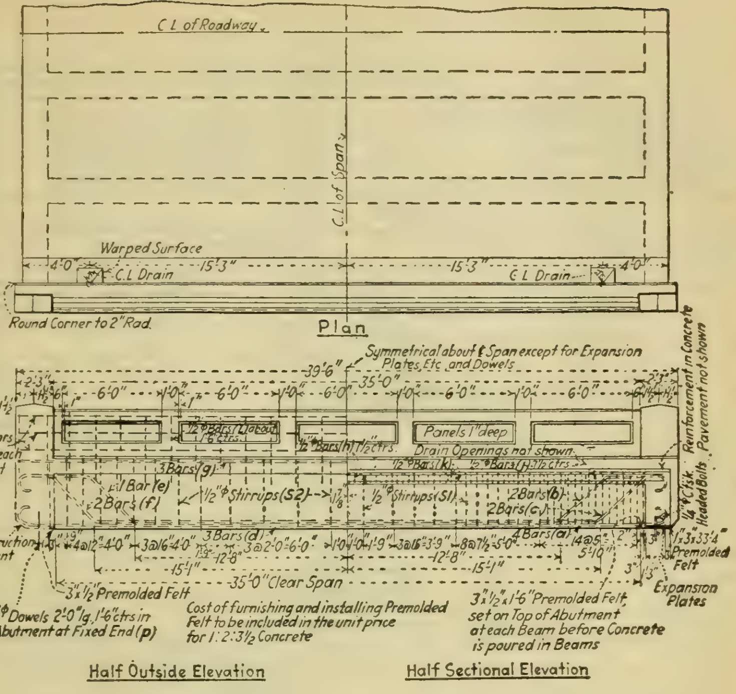


FIG. 73A.—N. Y. State. Typical T beam bridge. H-20 loading. (35 span).



NOTES

Camber bridge 1/16″ per foot of bridge span.

The above bar list makes no provision for splicing reinforcing bars except ongitudinal mat bars. The ½″φ reinforcing bars may be spliced at places ipproved by the Engineer. Bars so spliced shall be lapped 40 diameters, and paced to allow 1″ of concrete between surfaces.

All concrete except in concrete pavement to be "Nominal Mix 1:2:3½–200 #/□″.

Concrete in wearing surface to be "Nominal Mix 1:1½:3–2500 #/□″.

No construction joints other than shown on the plans will be permitted. The construction joint on the center line of roadway will be permitted only vhen approved by the Engineer in writing. Construction joints to be free rom laitance.

The lower expansion plate shall be placed on the top of the abutment before he concrete in the abutment has set.

A layer of graphite axle grease about ⅛″ thick shall be placed between the xpansion plates before the concrete is poured in the beam-stems.

Curbs, slab and beam-stems must be poured at the same time, allowing no time for initial set to take place between them.

All reinforcing bars shall be of medium open hearth steel. All dimensions or bending reinforcing bars except as noted are center to center of bars.

All parapet, fascia and curb surfaces shall be given a rubbed finish, cost o be included in unit price for 1:1½:3 concrete.

For name plate, see sheet and specifications.

FIG. 73A.—(*Continued.*)

MATERIAL REQUIRED (no overrun or rounding)	
79.2 Cu. Yds 1:2:3½ Concrete	16.7 Cu. Yds. 1:1½:3 Concrete
168¼ Bbls. Cement	1740 Lb. Structural Steel
17,190 Lb. Metal Reinforcement	1056 Sq. Ft. Waterproofing

BAR LIST

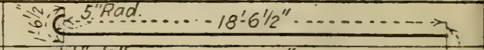
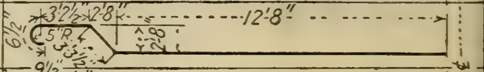
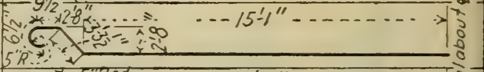
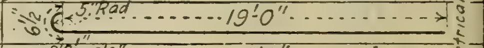
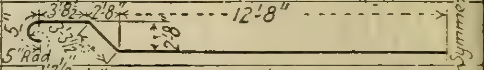
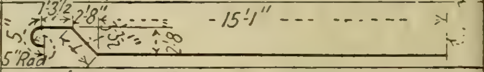
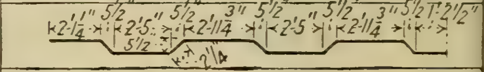
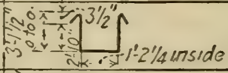
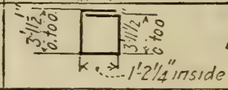
Mark	Number	Size	Length	Bending Diagram
a	16	1¼"□	40'-2"	
b	8	1¼"□	42'-5"	
c	8	1¼"□	42'-5"	
d	6	1¼"□	41'-1"	
e	2	1⅛"□	43'-2"	
f	4	1⅛"□	43'-2"	
g	6	1"□	39'-0"	Exterior Beams, Top
h	57	½"φ	34'-8"	
j	114	½"φ	32'-10"	Transverse Slab Bars, Top and Bottom
k	27	½"φ	38'-0"	Longitudinal Slab Bars, Top and Bottom
l	54	½"φ	4'-4"	Vertical Bars in Curbs and Parapet
m	6	½"φ	39'-2"	Longitudinal Bars in Parapet
n	117	¼"φ	8'-6"	Bar Mat. Reinforcement Transverse Bars
o	81	¼"φ	13'-4"	Bar Mat. Reinforcement Longitudinal Bars
p	22	¾"φ	2'-0"	Dowels in Fixed Abutments
S1	224	½"φ	8'-2"	 Interior Stringers
S2	52	½"φ	11'-6"	 Exterior Stringers

FIG. 73*A*.—Bar list 35 ft. clear span.—(*Continued.*)

TABLE OF DIMENSIONS AND REINFORCEMENT N. Y. STATE STANDARD REINFORCED CONCRETE STRINGER BEAM BRIDGES H-20 LOADING 30 FT. ROADWAY

Clear span between abutments	Number T beams	C to C T beams, inches	Depth T beam below floor slab, inches	Width T beam, inches	Depth floor slab (exclusive of pavement concrete)	Reinforcement						
						T beam (each)				Slab (long. bar)		
						Number long. bars	Size	Stirrups number	Size	Size	Spacing	
											Bottom	Top
25	6	6′ 03¾″	1′ 07″	1′ 06″	8″	8	1¼″ □	52	½″ϕ	½″ϕ	3¾″	7½″
26	6	6′ 03¾″	1′ 08″	1′ 06″	8″	8	1¼″ □	50	½″ϕ	½″ϕ	3¾″	7½″
28	6	6′ 03¾″	1′ 10″	1′ 06″	8″	8	1¼″ □	50	½″ϕ	½″ϕ	3¾″	7½″
30	6	6′ 03¾″	2′ 00″	1′ 06″	8″	8	1¼″ □	50	½″ϕ	½″ϕ	3¾″	7½″
32	6	6′ 03¾″	2′ 04″	1′ 06″	8″	8	1¼″ □	50	½″ϕ	½″ϕ	3¾″	7½″
34	6	6′ 03¾″	2 07″	1′ 06″	8″	8	1¼″ □	50	½″ϕ	½″ϕ	3¾″	7½″
35	6	6′ 03¾″	2′ 08″	1′ 06″	8″	8	1¼″ □	50	½″ϕ	½″ϕ	3¾″	7½″
36	6	6′ 03¾″	2′ 10″	1′ 06″	8″	8	1¼″ □	50	½″ϕ	½″ϕ	3¾″	7½″
38	6	6′ 03¾″	3′ 02″	1′ 06″	8″	8	1¼″ □	46	½″ϕ	½″ϕ	3¾″	7½″
40	6	6′ 03¾″	3′ 06″	1′ 06″	8″	8	1¼″ □	48	½″ϕ	½″ϕ	3¾″	7½″
42	6	6′ 03¾″	3′ 10″	1′ 06″	8″	8	1¼″ □	44	½″ϕ	½″ϕ	3¾″	7½″

FIG. 73A.—(*Continued.*)

QUANTITY FOR BEAM BRIDGES

Span	Metal reinforcement, pounds	Structural steel, pounds	Cement, barrels	1:2:3½ concrete, cubic yards	1:1½:3 concrete, cubic yards	Waterproofing, square feet	Estimated cost 1925	Slab transverse bars		
								Size	Spacing	
									Bottom	Top
25	12,200	1,400	102	45.5	12.3	768	$2,650			
26	12,630	1,400	107	48.1	12.7	796	2,770			
28	13,720	1,400	117	53.2	13.5	850	3,020			
30	14,630	1,400	129	58.7	14.3	905	3,255			
32	15,590	1,740	148	68.6	15.4	974	3,680			
34	16,670	1,740	162	76.0	16.3	1,029	3,990			
35	17,190	1,740	168	79.2	16.7	1,056	4,035	½″ϕ	See plan	See plan
36	17,550	1,740	177	83.7	17.1	1,084	4,310			
38	18,450	2,080	199	95.7	18.2	1,152	4,795			
40	19,700	2,080	218	105.7	19.1	1,207	5,200			
42	20,640	2,080	237	116.2	19.8	1,262	$5,615			

FIG. 73A.—(*Continued.*)

QUANTITIES IN CONCRETE DECK GIRDER HIGHWAY BRIDGES.
U. S. BUREAU OF PUBLIC ROADS.

Span, ft.	16-ft. roadway		18-ft. roadway		20-ft. roadway		24-ft. roadway	
	Concrete, cu. yd.	Steel, lb.	Concrete, cu. yd.	Steel, lb.	Concrete, cu. yd.	Steel, lb.	Concrete, cu. yd.	Steel, lb.
16	14.3	2,820	15.3	3,160	16.5	3,510	19.2	3,980
18	16.0	3,130	17.7	3,520	19.0	3,880	22.2	4,430
20	17.8	3,770	19.3	4,330	21.2	4,760	24.2	5,470
22	20.1	4,100	21.8	4,690	23.3	5,140	27.4	5,930
24	22.3	4,460	23.6	5,710	25.7	6,230	29.6	7,220
26	23.8	5,260	25.7	6,140	28.0	6,670	32.4	7,770
28	29.1	5,870	30.2	7,070	32.8	7,440	37.7	8,940
30	32.6	6,260	34.1	7,570	36.9	7,980	42.5	9,580
32	34.6	7,560	38.1	8,100	41.2	8,500	47.6	10,240
34	38.3	8,100	42.5	8,580	43.5	10,180	53.0	10,850
36	42.2	8,550	45.5	10,300	47.9	10,770	56.6	13,040
38	46.4	9,070	50.1	10,910	52.8	11,420	62.5	13,810
40	50.8	9,540	55.0	11,520	57.8	12,030	68.6	14,600

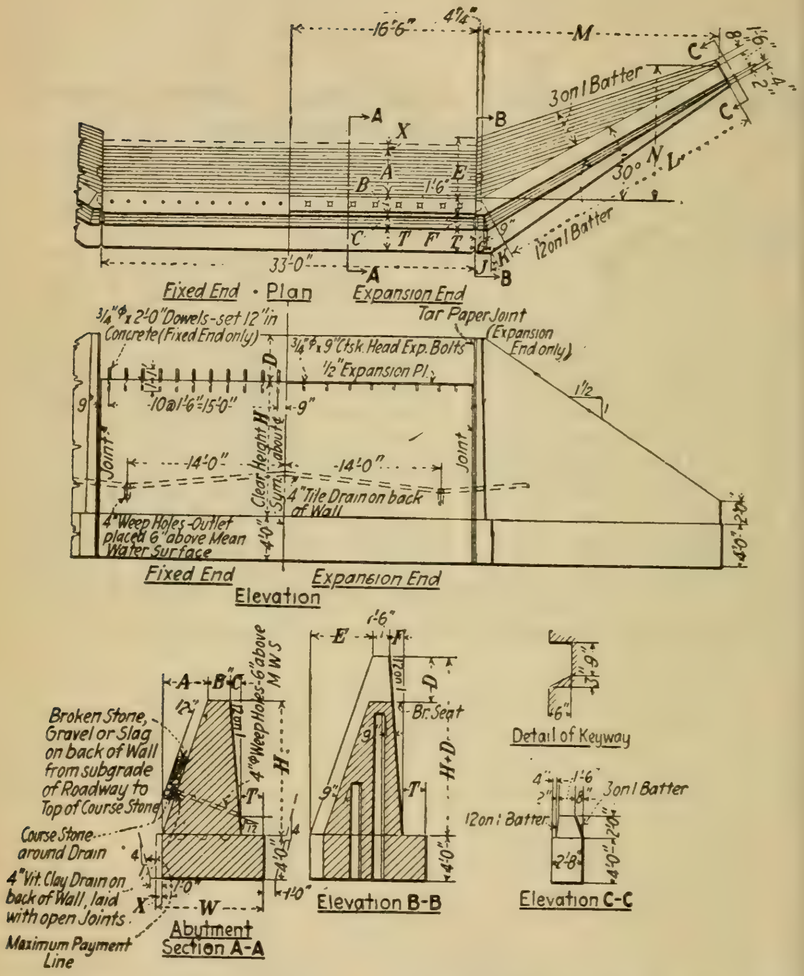


FIG. 73B.—Standard abutments for T beam bridges. New York State 1926. (Dimensions pages 260–264.)

NOTE.—Designed for ordinary soils. Base width can be reduced on gravel, hardpan or rock.

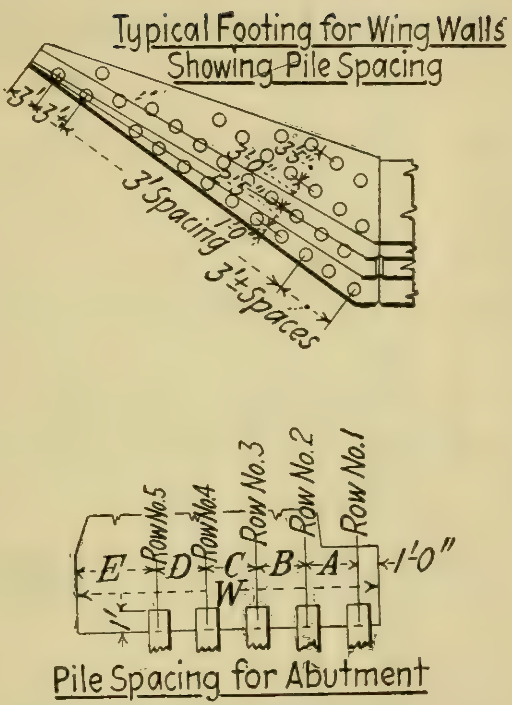


FIG. 73B.—(*Continued.*)

Clear span, feet	H	Abutment							
		A	B	C	Footing			Cu. yds. concrete 1–2½–5	Toe pressure, tons sq. ft.
					W	T	X		
25 and 26	8	3′– 0″	1′–6″	8″	6′– 8″	1′– 6″	0	65.2	1.9
	10	3′–10″	1′–6″	10″	7′– 9″	1′– 7″	0	84.6	2.2
	12	4′– 8″	1′–6″	1′–0″	8′–10″	1′– 8″	0	106.2	2.3
	14	5′– 6″	1′–6″	1′–2″	9′–11″	1′– 9″	0	131.2	2.5
	16	6′– 4″	1′–6″	1′–4″	10′–11″	1′– 9″	0	157.5	2.7
28	8	3′– 0″	1′–6″	8″	6′– 8″	1′– 6″	0	65.2	2.1
	10	3′–10″	1′–6″	10″	7′– 9″	1′– 7″	0	84.6	2.3
	12	4′– 8″	1′–6″	1′–0″	8′–10″	1′– 8″	0	106.8	2.4
	14	5′– 6″	1′–6″	1′–2″	9′–11″	1′– 9″	0	131.2	2.6
	16	6′– 4″	1′–6″	1′–4″	10′–11″	1′– 9″	0	157.5	2.8
30	8	3′– 0″	1′–6″	8″	6′– 8″	1′– 6″	0	65.2	2.2
	10	3′–10″	1′–6″	10″	7′– 9″	1′– 7″	0	84.6	2.3
	12	4′– 8″	1′–6″	1′–0″	8′–10″	1′– 8″	0	106.8	2.5
	14	5′– 6″	1′–6″	1′–2″	9′–11″	1′– 9″	0	131.2	2.6
	16	6′– 4″	1′–6″	1′–4″	10′–11″	1′– 9″	0	157.5	2.8
32	10	3′– 5″	1′–9″	10″	7′– 8″	1′– 8″	0	85.0	2.4
	12	4′– 3″	1′–9″	1′–0″	8′– 9″	1′– 9″	0	106.9	2.6
	14	5′– 2″	1′–9″	1′–2″	9′–11″	1′–10″	0	132.8	2.7
	16	6′– 1″	1′–9″	1′–4″	11′– 1″	1′–11″	0	160.8	2.9
	18	7′– 0″	1′–9″	1′–6″	12′– 3″	2′– 0″	0	191.8	3.0
34 and 35	10	3′– 5″	1′–9″	10″	7′– 8″	1′– 8″	0	85.0	2.5
	12	4′– 3″	1′–9″	1′–0″	8′– 9″	1′– 9″	0	106.9	2.7
	14	5′– 2″	1′–9″	1′–2″	9′–11″	1′–10″	0	132.8	2.8
	16	6′– 1″	1′–9″	1′–4″	11′–1″	1′–11″	0	160.8	2.9
	18	7′– 0″	1′–9″	1′–6″	12′–4″	2′– 1″	0	192.2	3.0
36	10	3′– 5″	1′–9″	10″	7′– 8″	1′– 8″	0	85.0	2.6
	12	4′– 3″	1′–9″	1′–0″	8′–10″	1′–10″	0	107.3	2.6
	14	5′– 2″	1′–9″	1′–2″	10′– 1″	2′– 0″	0	133.3	2.7
	16	6′– 1″	1′–9″	1′–4″	11′– 3″	2′– 1″	0	161.6	2.9
	18	7′– 0″	1′–9″	1′–6″	12′– 5″	2′– 2″	0	192.6	3.0

FIG. 73B.—(*Continued.*)

38	12	4′– 0″	2′–0″	1′–0″	9′– 0″	2′– 0″	0	110.0	2.6
	14	4′–10″	2′–0″	1′–2″	10′– 2″	2′– 2″	0	135.3	2.7
	16	5′– 9″	2′–0″	1′–4″	11′– 5″	2′– 4″	0	164.2	2.8
	18	6′– 8″	2′–0″	1′–6″	12′– 8″	2′– 6″	0	195.8	2.9
	20	7′– 7″	2′–0″	1′–8″	14′– 0″	2′– 9″	0	230.3	3.0
40	12	4– 0″	2′–0″	1′–0″	9′– 0″	2′– 0″	0	110.0	2.7
	14	4′–10″	2′–0″	1′–2″	10′– 2″	2′– 2″	0	135.5	2.8
	16	5′– 9″	2′–0″	1′–4″	11′– 5″	2′– 4″	0	164.2	2.9
	18	6′– 8″	2′–0″	1′–6″	12′– 8″	2′– 6″	0	195.8	3.0
	20	7′– 7″	2′–0″	1′–8″	14′– 6″	2′– 9″	0′–6″	233.0	3.0
42	12	4′– 0″	2′–0″	1′–0″	9′– 0″	2′– 0″	0	110.0	2.8
	14	4′–10″	2′–0″	1′–2″	10′– 2″	2′– 2″	0	135.5	2.8
	16	5′– 9″	2′–0″	1′–4″	11′– 5″	2′– 4″	0	164.2	3.0
	18	6′– 8″	2′–0″	1′–6″	12′–10″	2′– 8″	0	196.5	3.0
	20	7′– 7″	2′–0″	1′–8″	14′– 6″	2′– 9″	0′– 6″	233.0	3.0

NOTES

The abutments and wing walls shown on this drawing are typical only. The Engineer will give definite elevations and dimensions for each bridge.

The depth of footings shall be determined with respect to the character of the foundation material and the possibility of undermining. All footings shall rest on a firm foundation and except where rock is encountered, shall be at a depth at least four feet below the bed of stream or surface of ground.

The wing walls shall be designed and detailed to suit existing conditions and the angle between abutment and wing wall and the relative elevations of footings, shall be made to fit the ground.

In case it appears that the soil will not safely withstand the unit pressure noted in the above table of abutment dimensions, timber piles shall be used and spaced as shown in the table. These piles are designed for a maximum load of 15 tons. The tops of piles shall be placed below low water elevation and the estimated length of piles to be used shall be shown on the plans. In case excessive erosive action of stream is expected, piles shall be used, rip-rap, placed in front of the abutment, or other approved means taken to prevent erosion.

Concrete in abutments and wing walls shall be 1–2½–5 mix, Item 21.

Keyways between abutments and wing walls and at all horizontal joints shall comprise about 30% of the area of surface.

All exposed edges of concrete shall be chamfered one inch.

The bases of structures shown on this sheet shall be considered as approximate only, and may be ordered in writing by the Engineer, to be at any elevation and of any dimensions necessary to give a proper foundation.

Payment for furnishing and placing dowels, expansion plates and bolts will be made at the respective contract prices for Metal Reinforcement and Structural Steel (see superstructure details).

Cost of furnishing and placing material in expansion joints at ends of bridge seat will be included in the price for Item 21.

4″ vitrified clay drains on the back of abutments will be paid for under Item 7.

Porous material placed on back of wall will be paid for under Items 61, 62 and 63.

FIG. 73*B*.—(*Continued.*)

Clear span, feet	Wing walls											
	H	D	H + D	E	F	G	J	K	L	M	N	Cu. yds. 1–2½–5 concrete two wings
25 and 26	8	2′– 3″	10′– 3″	3′– 5¼″	10¼″	11¾″	1′– 4½″	1′–0¼″	14′– 3½″	12′– 4½″	7′–1¾″	43.0
	10	2′– 3″	12′– 3″	4′– 1½″	1′– 0¼″	1′–0¼″	1′– 5¼″	1′–1″	17′– 9″	15′– 4½″	8′–10½″	61.8
	12	2′– 3″	14′– 3″	4′– 9½″	1′– 2¼″	1′–1″	1′– 6″	1′–1¾″	21′– 2½″	18′– 4½″	10′– 7¼″	85.8
	14	2′– 3″	16′– 3″	5′– 6″	1′– 4¼″	1′–1½″	1′– 7″	1′–2¾″	24′– 8¼″	21′– 4½″	12′– 4″	113.6
	16	2′– 3″	18′– 3″	6′– 2½″	1′– 6¼″	1′–2″	1′– 7¾″	1′–3½″	28′– 1¾″	24′– 4½″	14′– 1″	146.8
28	8	2′– 5″	10′– 5″	3′– 6″	10½″	11¾″	1′– 4½″	1′–0¼″	14′– 7″	12′– 7½″	7′– 3½″	44.2
	10	2′– 5″	12′– 5″	4′– 2¼″	1′– 0½″	1′–0¼″	1′– 5¼″	1′–1″	18′– 0½″	15′– 7½″	9′– 0¼″	63.8
	12	2′– 5″	14′– 5″	4′–10½″	1′– 2½″	1′–1″	1′– 6″	1′–1¾″	21′– 6″	18′– 7½″	10′– 9″	87.4
	14	2′– 5″	16′– 5″	5′– 6¾″	1′– 4½″	1′–1½″	1′– 7″	1′–2¾″	24′–11½″	21′– 7½″	12′– 5¾″	116.4
	16	2′– 5″	18′– 5″	6′– 3¼″	1′– 6½″	1′–2″	1′– 7¾″	1′–3½″	28′– 5¼″	24′– 7½″	14′– 2½″	149.8
30	8	2′– 7″	10′– 7″	3′– 6½″	10½″	11¾″	1′– 4½″	1′–0¼″	14′–10½″	12′–10½″	7′– 5¼″	45.6
	10	2′– 7″	12′– 7″	4′– 2¾″	1′– 0½″	1′–0¼″	1′– 5¼″	1′–1″	18′– 4″	15′–10½″	9′– 2″	65.2
	12	2′– 7″	14′– 7″	4′–11″	1′– 2½″	1′–1″	1′– 6″	1′–1¾″	21′– 9½″	18′–10½″	10′–10¾″	89.2
	14	2′– 7″	16′– 7″	5′– 7½″	1′– 4½″	1′–1½″	1′– 7″	1′–2¾″	25′– 3″	21′–10½″	12′– 7½″	118.8
	16	2′– 7″	18′– 7″	6′– 3¾″	1′– 6½″	1′–2″	1′– 7¾″	1′–3½″	28′– 8½″	24′–10½″	14′– 4¼″	152.2
32	10	2′–11″	12′–11″	4′– 4¼″	1′– 1″	1′–0½″	1′– 6″	1′–1¾″	18′–11″	16′– 4½″	9′– 5½″	69.6
	12	2′–11″	14′–11″	5′– 0½″	1′– 3″	1′–1″	1′– 6¾″	1′–2½″	22′– 4½″	19′– 4½″	11′– 2¼″	94.6
	14	2′–11″	16′–11″	5′– 9″	1′– 5″	1′–1½″	1′– 7½′	1′–3¼″	25′–10″	22′– 4½″	12′–11″	124.2
	16	2′–11″	18′–11″	6′– 5¼″	1′– 7″	1′–2″	1′– 8¼″	1′–4″	29′– 3½″	25′– 4½″	14′– 7¾″	159.4
	18	2′–11″	20′–11″	7′– 1½″	1′– 9″	1′–2½″	1′– 9″	1′–4¾″	32′– 9″	28′– 4½″	16′– 4½″	200.8
34 and 35	10	3′– 2″	13′– 2″	4′– 5¼″	1′– 1¼″	1′–0½″	1′– 6″	1′–1¾″	19′– 4″	16′– 9″	9′– 8″	72.0
	12	3′– 2″	15′– 2″	5′– 1½″	1′– 3¼″	1′–1″	1′– 6¾″	1′–2½″	22′– 9¾″	19′– 9″	11′– 4¾″	97.8
	14	3′– 2″	17′– 2″	5′–10″	1′– 5¼″	1′–1½″	1′– 7½″	1′–3¼″	26′–3½″	22′– 9″	13′– 1¾″	128.4
	16	3′– 2″	19′– 2″	6′– 6¼″	1′– 7¼″	1′–2″	1′– 8¼″	1′–4″	29′– 8¾″	25′– 9″	14′–10½″	164.7
	18	3′– 2″	21′– 2″	7′– 2½″	1′– 9¼″	1′–2½″	1′– 9¼″	1′– 5″	33′– 2½″	28′– 9″	16′– 7¼″	207.2

FIG. 73*B*.—(*Continued.*)

36	10	3′- 5″	13′- 5″	4′- 6½″	1′- 1½″	1′-0½″	1′- 6″	1′-1¾″	19′- 9¼″	17′- 1½″	9′-11″	75.2
	12	3′- 5″	15′- 5″	5′- 2¾″	1′- 3½″	1′-1¼″	1′- 7″	1′-2¾″	23′- 3″	20′- 1½″	11′- 7½″	101.8
	14	3′- 5″	17′- 5″	5′-11″	1′- 5½″	1′-1¾″	1′- 8″	1′-3¾″	26′- 8½″	23′- 1½″	13′- 4¼″	133.6
	16	3′- 5″	19′- 5″	6′- 7½″	1′- 7½″	1′-2¼″	1′- 9″	1′-4¾″	30′- 2″	26′- 1½″	15′- 1″	170.6
	18	3′- 5″	21′- 5″	7′- 3¾″	1′- 9½″	1′-2¾″	1′- 9¾″	1′-5½″	33′- 7½″	29′- 1½″	16′- 9¾″	213.2
38	12	3′- 9″	15′- 9″	5′- 4″	1′- 3¾″	1′-1¼″	1′- 7¾″	1′-3½″	23′- 9¾″	20′- 7½″	11′-10¾″	107.0
	14	3′- 9″	17′- 9″	6′- 0½″	1′- 5¾″	1′-1¾″	1′- 8¾″	1′-4½″	27′- 3½″	23′- 7½″	13′- 7¾″	139.6
	16	3′- 9″	19′- 9″	6′- 8½″	1′- 7¾″	1′-2¼″	1′-10″	1′-5¾″	30′- 9″	26′- 7½″	15′- 4½″	178.2
	18	3′- 9″	21′- 9″	7′- 5″	1′- 9¾″	1′-2¾″	1′-11″	1′-6¾″	34′- 2½″	29′- 7½″	17′- 1¼″	222.8
	20	3′- 9″	23′- 9″	8′- 1¼″	1′-11¾″	1′-3¼″	2′- 0¼″	1′-8″	37′-8″	32′- 7½″	18′-10″	274.6
40	12	4′- 1″	16′- 1″	5′- 5¼″	1′- 4″	1′-1¼″	1′- 7¾″	1′-3½″	24′- 4¾″	21′- 1½″	12′- 2¼″	112.2
	14	4′- 1″	18′- 1″	6′- 1½″	1′- 6″	1′-1¾″	1′- 8¾″	1′-4½″	27′-10½″	24′- 1½″	13′-11″	145.6
	16	4′- 1″	20′- 1″	6′-10″	1′- 8″	1′-2¼″	1′-10″	1′-5¾″	31′- 4″	27′- 1½″	15′- 8″	185.0
	18	4′- 1″	22′- 1″	7′- 6¼″	1′-10″	1′-3″	1′-11″	1′-6¾″	34′- 9½″	30′- 1½″	17′- 4¾″	230.2
	20	4′- 1″	24′- 1″	8′- 2¾″	2′- 0″	1′-3½″	2′- 0¼″	1′-8″	38′- 3″	33′- 1½″	19′- 1½″	283.2
42	12	4′- 5″	16′- 5″	5′- 6¾″	1′- 4½″	1′-1½″	1′- 7¾″	1′-3½″	24′-11½″	21′- 7½″	12′- 5¾″	117.6
	14	4′- 5″	18′- 5″	6′- 3¼″	1′- 6½″	1′-2″	1′- 9″	1′-4¾″	28′- 5½″	24′- 7½″	14′- 2½″	152.0
	16	4′- 5″	20′- 5″	6′-11½″	1′- 8½″	1′-2½″	1′-10″	1′-5¾″	31′-10¾″	27′- 7½″	15′-11¼″	192.4
	18	4′- 5″	22′- 5″	7′- 7¾″	1′-10½″	1′-3″	1′-11½″	1′-7¼″	35′- 4¼″	30′- 7½″	17′- 8″	239.6
	20	4′- 5″	24′- 5″	8′- 4¼″	2′- 0½″	1′-3½″	2′- 0¼″	1′-8″	38′-10″	33′- 7½″	19′- 5″	292.6

FIG. 73*B*.—(*Continued.*)

Clear height H	Span of bridge	Width of base W	A	B	C	D	E	Longitudinal spacing Row 1	Row 2	Row 3	Row 4	Row 5
8	26′–30′	6′–8″	4′–0″	.....	.....	.....	1′– 8″	2′–6″	2′–6″			
10	26′–30′	7′– 9″	4′–0″	.....	.....	.....	2′– 9″	3′–0″	3′–0″			
	32′–36′	7′– 8″	4′–0″	.....	.....	.....	2′– 8″	2′–6″	2′–6″			
12	26′–30′	8′–10″	4′–6″	.....	.....	.....	3′– 4″	2′–6″	2′–6′			
	32′–34′	8′– 9″	2′–6″	2′–6″	.....	.....	2′– 9″	3′–0″	3′–0″	3′–0″		
	36′	8′–10″	2′–6″	2′–6″	.....	.....	2′–10″	3′–0″	3′–0″	3′–0″		
	38′–42′	9′– 0″	2′–6″	2′–6″	.....	.....	3′– 0″	3′–0″	3′–0″	3′–0″		
14	26′–34′	9′–11″	2′–6″	3′–6″	.....	.....	2′–11″	2′–6″	2′–6″	2′–6″		
	36′	10′– 1″	2′–6″	3′–6″	.....	.....	3′– 1″	2′–6″	2′–6″	2′–6″		
	38′–42′	10′– 2″	2′–6″	3′–6″	.....	.....	3′– 2″	2′–6″	2′–6″	2′–6″		
16	26′–30′	10′–11″	2′–6″	5′–0″	.....	.....	2′–5″	2′–6″	2′–6′	2′–6″		
	32′–34′	11′– 1″	2′–6″	5′–0″	.....	.....	2′– 7″	2′–6″	2′–6″	2′–6″		
	36′	11′– 3″	2′–6″	5′–0″	.....	.....	2′– 9″	2′–6″	2′–6″	2′–6″		
	38′–42′	11′– 5″	2′–6″	5′–0″	.....	.....	2′–11″	2′–6″	2′–6″	2′–6″		
18	32′	12′– 3″	2′–6″	2′–6″	3′–6″	.....	2′– 9″	2′–6″	2′–6″	2′–6″	2′–6″	
	34′	12′– 4″	2′–6″	2′–6″	3′–6″	.....	2′–10″	2′–6″	2′–6″	2′–6″	2′–6″	
	36′	12′– 5″	2′–6″	2′–6″	3′–6″	.....	2′–11″	2′–6″	2′–6″	2′–6″	2′–6″	
	38′–40′	12′– 8″	2′–6″	3′–0″	4′–0″	.....	2′– 2″	2′–6″	2′–6″	2′–6″	2′–6″	
	42′	12′–10″	2′–6″	3′–0″	4′–0″	.....	2′– 4″	2′–6″	2′–6″	2′–6″	2′–6″	
20	38′	14′– 0″	2′–6″	3′–5″	4′–0″	.....	3′–0″	2′–6″	2′–6″	2′–6″	2′–6″	
	40′–42′	14′– 6″	2′–6″	2′–6″	2′–6″	2′–6″	3′–6″	2′–6″	2′–6″	2′–6″	2′–6″	2′–6″

Estimated length of piles = 20′–0″.

Fig. 73*B*.—(*Continued.*)

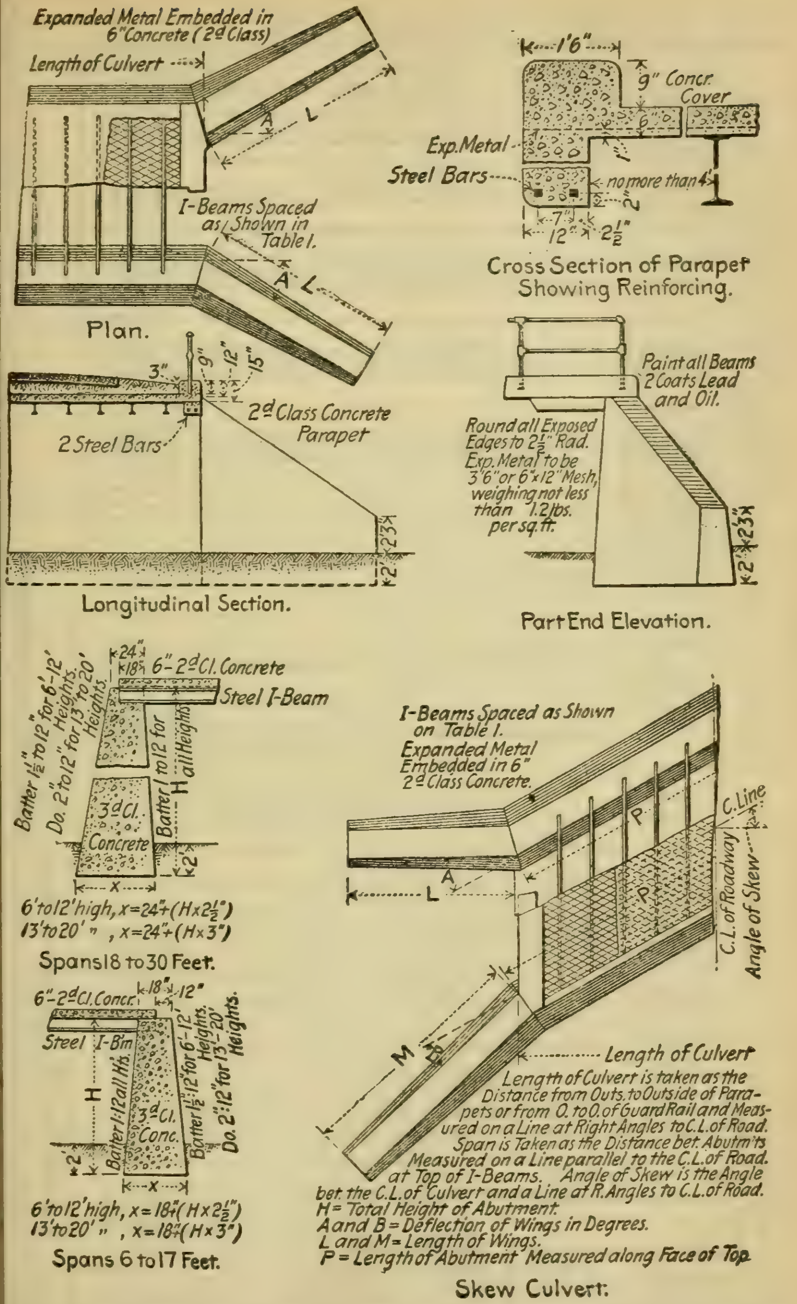


FIG. 74.—New York State I-beam bridges (1912). **H-12½ loading.** (Dimensions pages 266–269.)

Span, all Culverts	Opening at Right Angles to Faces of Abutments			Steel I-Beams					Steel Bars		Sq. feet E'x'p'dMet.		Cu. Yds. 2d Class Concrete Cover and Parapets		Ft. B. M. Lumber		Pounds Spikes and Nails	Lin. ft. Bridge Rail	Lin. ft. Pipe Rail
	15° Skew	30° Skew	45° Skew	Depth Inches	Spacing	Length feet	Wt. per ft.	Wt. of Beam	Size	Weight of 4 Bars	25 foot Length	Per foot Length	25 foot Length	Per foot Length	25 foot Length	Per foot Length			
6	5.80	5.20	4.24	6		8	12¼	100	¾"	61	200	8	4.54	0.15	855	30	24	20	16
7	6.76	6.06	4.95	7		9	15	135	¾"	69	225	9	5.08	0.17	952	33	26	22	18
8	7.73	6.93	5.66	7		10	15	150	¾"	76	250	10	5.63	0.19	1042	36	28	24	20
9	8.69	7.79	6.36	8	2'-9"	11	18	198	¾"	84	275	11	6.63	0.20	1143	39	30	26	22
10	9.66	8.66	7.07	9	3'-0"	12	21	252	¾"	92	300	12	7.28	0.22	1234	42	32	28	24
11	10.63	9.53	7.78	9	3'-0"	13	21	273	⅞"	135	325	13	7.88	0.24	1325	45	34	30	26
12	11.59	10.39	8.49	9	2'-6"	14	21	294	⅞"	146	350	14	8.48	0.26	1431	48	36	32	28
13	12.56	11.26	9.19	10	3'-0"	15	25	375	1 "	204	375	15	9.16	0.28	1523	51	38	34	30
14	13.52	12.12	9.90	10	2'-9"	16	25	400	1 "	218	400	16	9.78	0.30	1633	54	40	36	32
15	14.49	12.99	10.61	12	3'-0"	17	31½	535½	1 "	231	425	17	10.56	0.31	1727	57	42	38	34
16	15.45	13.86	11.31	12	3'-0"	18	31½	567	1 "	245	450	18	11.19	0.33	1820	60	44	40	36
17	16.42	14.72	12.02	12	3'-0"	19	31½	598½	1⅛"	327	475	19	11.81	0.35	1956	63	46	42	38
18	17.39	15.59	12.73	12	3'-0"	21	31½	661½	1⅛"	361	525	21	12.90	0.39	2052	66	48	44	40
19	18.35	16.46	13.44	12	2'-9"	22	31½	693	1⅛"	378	550	22	13.51	0.41	2148	69	50	46	42
20	19.32	17.32	14.14	15	3'-0"	23	42	966	1⅛"	396	575	23	14.51	0.43	2244	72	52	48	44
21	20.28	18.19	14.85	15	3'-0"	24	42	1008	1¼"	510	600	24	15.14	0.44	2340	75	54	50	46
22	21.26	19.05	15.56	15	3'-0"	25	42	1050	1¼"	531	625	25	15.79	0.46	2519	78	56	52	48
23	22.22	19.92	16.26	15	3'-0"	26	42	1092	1¼"	552	650	26	16.43	0.48	2618	81	58	54	50
24	23.18	20.78	16.97	15	3'-0"	27	42	1134	1⅜"	694	675	27	17.08	0.50	2718	84	60	56	52
25	24.15	21.65	17.68	15	2'-9"	28	42	1176	1⅜"	720	700	28	17.72	0.52	2818	87	62	58	54
26	25.11	22.52	18.38	15	2'-6"	29	42	1218	1½"	887	725	29	18.36	0.54	2918	90	64	60	56
27	26.08	23.38	19.09	18	3'-0"	30	55	1650	1½"	918	750	30	19.50	0.56	3018	93	66	62	58
28	27.05	24.25	19.80	18	3'-0"	31	55	1705	1½"	949	775	31	20.16	0.57	3222	96	68	64	60
29	28.01	25.11	20.51	18	3'-0"	32	55	1760	1½"	979	800	32	20.82	0.59	3326	99	70	66	62
30	28.98	25.98	21.23	18	3'-0"	33	55	1815	1½"	1010	825	33	21.48	0.61	3430	102	72	68	64

NOTE: Length of Bars in Parapets same as lengths of I-Beams.

FIG. 74.—(*Continued.*)

Table No. 2			Straight A = 30° B = 30°						Table No. 3		15° Skew A = 30° B = 15°					
Height of Abutment	Lengths of Wings		Cubic Yards Third Class Concrete		Cubic Yards Third Class Masonry		Cubic Yds. each ft. in length of Culvert more or less than 25 ft.		Lengths of Wings		Cubic Yards Third Class Concrete		Cubic Yards Third Class Masonry		Cubic Yds. each ft. in length of Culvert more or less than 25 ft.	
H	L	M	2 Abut's	4 Wings	2 Abut's	4 Wings	Concrete	Masonry	L	M	2 Abut's	4 Wings	2 Abut's	4 Wings	Concrete	Masonry
6	3.87	3.87	23.3	5.5	28.5	6.5	0.94	1.17	3.51	3.67	24.2	5.2	29.7	6.1	0.98	1.21
7	5.60	5.60	28.3	9.2	34.3	10.9	1.17	1.41	5.06	5.40	29.6	8.8	36.0	10.4	1.20	1.47
8	7.33	7.33	34.0	13.8	40.5	16.4	1.38	1.68	6.62	7.13	35.4	12.9	42.7	15.5	1.44	1.74
9	9.06	9.06	40.0	19.4	47.3	22.7	1.63	1.95	8.16	8.86	41.6	18.3	49.6	21.6	1.69	2.03
10	10.79	10.79	46.4	25.4	54.5	30.2	1.88	2.25	9.72	10.59	48.2	24.3	57.2	28.8	1.95	2.33
11	12.52	12.52	53.3	33.4	62.3	39.1	2.16	2.56	11.27	12.32	55.2	31.7	65.1	37.1	2.24	2.66
12	14.26	14.26	60.8	42.1	70.5	49.1	2.44	2.89	12.82	14.06	62.5	39.9	73.5	46.6	2.54	3.00
13	15.99	15.99	72.2	55.5	84.7	64.3	3.01	3.49	14.38	15.79	76.8	53.0	88.4	61.3	3.12	3.62
14	17.72	17.72	81.5	68.4	94.2	78.5	3.37	3.89	15.53	17.52	86.0	64.5	98.6	74.4	3.50	4.04
15	19.45	19.45	91.0	82.4	104.2	94.0	3.75	4.31	17.48	19.25	95.7	73.4	109.3	89.6	3.89	4.47
16	21.18	21.18	101.0	98.2	114.5	111.4	4.15	4.74	19.11	20.98	106.0	93.7	120.5	106.3	4.31	4.92
17	22.92	22.92	111.1	115.9	125.3	130.7	4.56	5.19	20.58	22.72	116.1	110.1	131.8	124.5	4.74	5.39
18	24.65	24.65	121.8	134.4	136.3	152.6	5.00	5.67	22.14	24.45	127.1	128.8	143.7	145.0	5.19	5.88
19	26.38	26.38	132.7	156.2	147.7	175.7	5.45	6.16	23.69	26.18	138.3	149.0	155.8	167.3	5.66	6.38
20	28.11	28.11	144.0	179.5	159.5	201.4	5.93	6.67	25.24	27.91	150.2	170.8	168.4	191.6	6.15	6.91

Fig. 74.—(*Continued.*)

Table No. 4			30° Skew A = 30° B = 15°					
Height of Abutment	Lengths of Wings		Cubic Yards Third Class Concrete		Cubic Yards Third Class Masonry		Cubic Yds. each ft. in length of Culverts more or less than 25 ft.	
H	L	M	2 Abut's	4 Wings	2 Abut's	4 Wings	Concrete	Masonry
6	3.4	4.44	27.0	5.6	33.3	6.8	1.09	1.35
7	4.9	6.56	32.8	8.8	40.2	11.3	1.33	1.63
8	6.4	8.69	39.5	14.4	47.6	17.0	1.59	1.94
9	7.9	10.81	46.3	20.2	55.7	23.8	1.87	2.26
10	9.4	12.93	53.7	26.9	64.0	31.7	2.17	2.60
11	10.9	15.05	61.6	34.7	72.9	40.9	2.48	2.95
12	12.4	17.17	70.0	43.7	82.3	51.4	2.82	3.34
13	13.9	19.30	85.7	58.3	99.2	67.5	3.48	4.03
14	15.4	21.42	96.0	71.4	110.7	82.8	3.89	4.49
15	16.9	23.54	107.0	86.4	122.4	99.5	4.33	4.97
16	18.4	25.66	118.0	102.9	134.6	117.3	4.79	5.48
17	19.9	27.78	129.7	121.2	147.0	137.2	5.27	6.00
18	21.4	29.90	142.0	141.1	160.5	159.7	5.77	6.54
19	22.9	32.02	154.6	163.5	174.0	184.4	6.30	7.11
20	24.4	34.14	168.0	188.5	188.0	211.2	6.84	7.70

	Table No. 5		45° Skew A = 45° B = 0°					
Height of Abutment	Lengths of Wings		Cubic Yards Third Class Concrete		Cubic Yards Third Class Masonry		Cubic Yds. each ft. in length of Culvert more or less than 25 ft.	
H	L	M	2 Abut's	4 Wings	2 Abut's	4 Wings	Concrete	Masonry
6	3.6	4.24	33.0	5.5	40.5	6.8	1.34	1.65
7	5.1	6.36	40.5	9.7	49.5	11.2	1.63	2.00
8	6.6	8.49	48.3	14.5	58.8	17.1	1.95	2.37
9	8.1	10.81	57.0	20.3	68.5	23.8	2.29	2.76
10	9.6	12.73	66.0	27.2	78.5	31.8	2.66	3.18
11	11.1	14.85	75.4	35.0	89.2	41.0	3.04	3.63
12	12.6	16.97	85.5	44.1	100.5	51.4	3.46	4.09
13	14.1	19.10	105.0	58.8	121.5	67.9	4.26	4.94
14	15.6	21.22	117.6	71.8	135.3	83.0	4.76	5.50
15	17.1	23.54	130.8	87.1	149.8	99.4	5.31	6.09
16	19.6	25.46	144.7	103.6	165.0	117.4	5.87	6.71
17	20.1	27.58	159.0	121.6	180.6	137.8	6.46	7.35
18	21.6	29.70	173.0	141.8	197.0	159.7	7.08	8.02
19	23.1	31.82	189.6	164.1	213.9	184.7	7.72	8.71
20	24.6	33.94	206.0	189.1	232.0	211.6	8.39	9.43

FIG. 74.—(*Continued.*)

Table No. 6	Number I-Beams For Concrete Covers only			P = Length of Abutments		
Length of Culvert	Spacing					
	2′-6″	2′-9″	3′-0″	15° Skew	30° Skew	45° Skew
18	5	5	4	18.64	20.79	25.46
19	5	5	5	19.67	21.94	26.97
20	6	5	5	20.71	23.09	28.28
21	6	6	5	21.74	24.25	29.70
22	6	6	5	22.78	25.40	31.11
23	7	6	6	23.81	26.66	32.53
24	7	6	6	24.85	27.71	33.94
25	7	7	6	25.88	28.87	35.36
26	8	8	7	26.92	30.02	36.77
27	8	8	7	27.95	31.18	38.18
28	9	8	7	28.99	32.33	39.60
29	9	8	8	30.02	33.49	41.01
30	9	9	8	31.06	34.64	42.43
31	10	9	9	32.09	35.80	43.84
32	10	9	9	33.13	36.95	45.26
33	11	10	9	34.16	38.10	46.67

Application of Tables

Quantities for a 30° Skew Concrete Culvert, concrete top, length 30 feet, opening 13 feet high and 12 feet wide. From Table 1, an opening 12.12 ft. wide 30° Skew is a 14-ft. span requiring (see 30-ft. length, Table 6) 9 I-Beams spaced 2′-9″ c. to c. (9 × 400) = 3600 lbs. I-Beams; 218 lbs. Bars; 400 + (5 × 16) = 480 sq. ft. Ex'p'd Metal; 9.78 + (5 × 30) = 11.28 cu. yds. 2d class Concrete 32 lin. ft. Pipe Rail. An opening 13 ft. high will require Abutments, 16 ft. high (13′ + 2′ in ground + 10″ I-Beam = 15′-10″). From Table 4, Abutments = 118.0 cu. yds., Wings = 102.9 cu. yds. (5 × 4.79 = 23.95 cu. yds. 5 ft. extra length of Culvert) 118.0 + 102.9 + 23.95 = 244.85 cu. yds. 3d Class Concrete.

For Spans of more than 17 feet, use Masonry Tables for Concrete Abutments and Wings.

Fig. 74.—(*Continued.*)

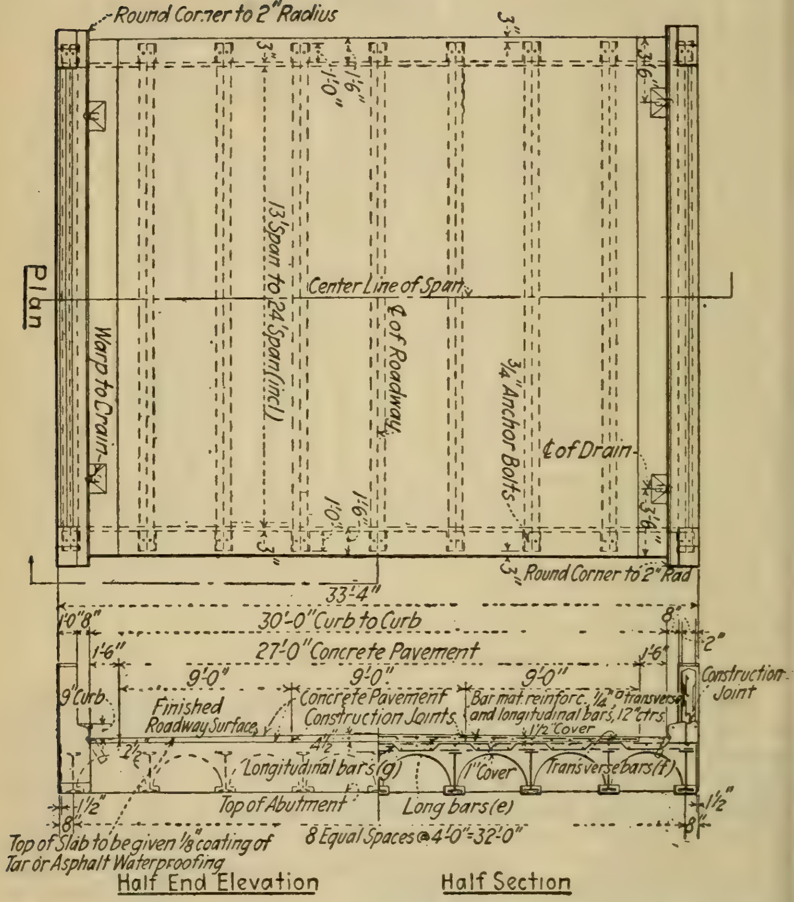


FIG. 75.—Steel I-beam stringer superstructures. (H-20 loading.) New York 1926. Spans 13 to 25 feet.

Detail dimensions pages 272–274. (Abutments for spans 13 to 25 feet, see page 241.)

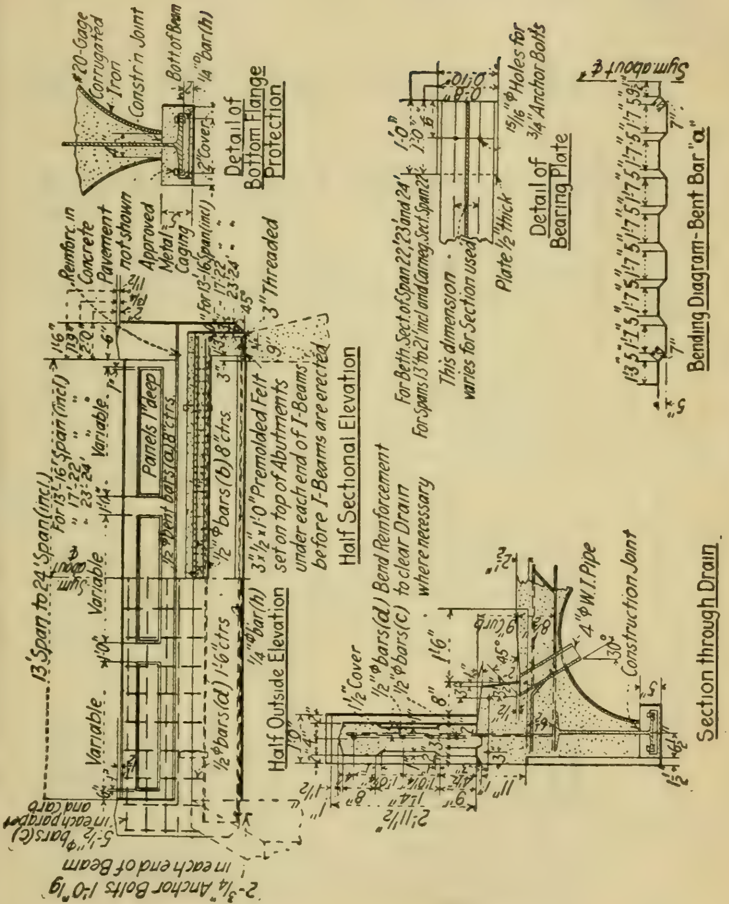


FIG. 75.—(Continued.)

Clear span, ft.	Section modulus required	I-beams				Summary of quantities required (no overrun or rounding)							
		Size	Type	No. req.	Length	Cu. yds. concrete		Bbls. cement	Lbs. metal reinforcement	Sq. ft. waterproofing	Sq. ft. corrugated iron	Lbs. structural steel
						1–1½–3	1–2–3½					
13	61.8	15″ –50#	Carnegie	9	15′–6″	7.0	25.4	57¼	2,120	439	460	7,290
	61.8	15⅗₃₂″–42.5#	Beth.	9	15′–6″	7.0	25.4	57¼	2,120	439	460	6,240
14	68.3	18″ –48.2#	Carnegie	9	16′–6″	7.4	29.2	64½	2,290	467	540	7,470
	68.3	18″ –49#	Beth.	9	16′–6″	7.4	29.2	64½	2,290	467	540	7,590
15	74.2	18″ –48.2#	Carnegie	9	17′–6″	7.9	30.7	68	2,420	494	570	7,910
	74.2	18″ –49#	Beth.	9	17′–6″	7.9	30.7	68	2,420	494	570	8,030
16	80.2	18″ –48.2#	Carnegie	9	18′–6″	8.2	32.3	71½	2,580	521	610	8,340
	80.2	18″ –49#	Beth.	9	18′–6″	8.2	32.3	71½	2,580	521	610	8,470
17	86.6	18″ –54.7#	Carnegie	9	19′–6″	8.7	33.7	75	2,730	549	650	9,910
	86.6	18″ –49#	Beth.	9	19′–6″	8.7	34.0	75½	2,730	549	650	8,910
18	93.2	18″ –60#	Carnegie	9	20′–6″	9.2	35.2	78½	2,890	576	680	11,380
	93.2	18 1/16″–52	Beth.	9	20′–6″	9.2	35.5	79	2,890	576	680	9,910
19	101.2	20″ –65.4#	Carnegie	9	21′–6″	9.6	38.4	84½	3,030	604	750	12,970
	101.2	20″ –59.5#	Beth.	9	21′–6″	9.6	38.8	85¼	3,030	604	750	11,830
20	108.1	20″ –65.4#	Carnegie	9	22′–6″	10.0	39.8	87¾	3,190	631	790	13,560
	108.2	20″ –59.5#	Beth.	9	22′–6″	10.0	40.3	88½	3,190	631	790	12,360
21	115.2	20″ –65.4#	Carnegie	9	23′–6″	10.4	41.6	91½	3,320	659	830	14,150
	115.3	20″ –59.5#	Beth.	9	23′–6″	10.4	41.9	92¼	3,320	659	830	12,900
22	123.2	20″ –75#	Carnegie	9	24′–6″	10.9	43.2	95½	3,490	686	870	16,850
	123.2	20⅛″ –64.5#	Beth	9	24′–6″	10.9	43.8	96½	3,490	686	870	14,600
23	133.7	24″ –74.2#	Carnegie	9	25′–6″	11.4	48.4	105¼	3,630	713	1,020	17,400
	130.0	18⅛″ –74#	Beth.	9	25′–6″	11.4	43.6	97	3,630	713	870	17,360
24	141.1	24″ –74.2#	Carnegie	9	26′–6″	11.8	50.2	109	3,780	741	1,060	18,070
	139.0	20″ –73#	Beth.	9	26′–6″	11.8	47.2	104	3,780	741	940	17,790

FIG. 75.—(*Continued.*)

NOTES

The above bar list makes no provision for splicing reinforcing bars except longitudinal ¼″ □ bars "e and h." Bars may be spliced at places approved by the Engineer. Bars so spliced shall be lapped 40 diameters and spaced to allow 1″ of concrete between them.

All concrete except in concrete pavement and parapet shall be Nominal Mix 1 : 2 : 3½″–2200#/□″.

Concrete in wearing surface and parapet to be Nominal Mix 1 : 1½ : 3–2500#/□″.

The concrete used for encasement of bottom flanges of I's shall be made of stone not to exceed ¾ inch in size.

No construction joints other than those shown on the plans will be permitted without written permission of the Engineer. Construction joints to be free from laitance.

All reinforcing bars and structural steel shall be of medium open hearth steel. All dimensions for bending reinforcing bars are center to center of bars.

All parapet, fascia and curb surfaces shall be given a rubbed finish, cost to be included in the unit price for 1 : 1½ : 3 concrete.

The cost of furnishing and installing pipe drains, metal caging and premoulded felt strips shall be included in the unit price for 1 : 2 : 3½ concrete.

FIG. 75.—(*Continued.*)

Bar list									
Clear span, ft.	Mark	No.	Size	Length	Clear span, ft.	Mark	No.	Size	Length
13	*a*	21	½″ϕ	35′– 7″	14	*a*	22	½″ϕ	35′– 7″
	b	40	½″ϕ	32′–11″		*b*	44	½″ϕ	32′–11″
	c	10	½″ϕ	15′– 8″		*c*	10	½″ϕ	16′– 8″
	d	24	½″ϕ	4′– 2″		*d*	26	½″ϕ	4′– 2″
	e	27	¼″□	15′– 6″		*e*	54	¼″□	8′– 8″
	f	48	¼″□	8′– 8″		*f*	51	¼″□	8′– 8″
	g	33	½″ϕ	15′– 6″		*g*	33	½″ϕ	16′– 6″
	h	18	¼″□	12′– 6″		*h*	18	¼″□	13′– 6″
15	*a*	24	½″ϕ	35′– 7″	16	*a*	25	½″ϕ	35′– 7″
	b	46	½″ϕ	32′–11″		*b*	50	½″ϕ	32′–11″
	c	10	½″ϕ	17′– 8″		*c*	10	½″ϕ	18′– 8″
	d	26	½″ϕ	4′– 2″		*d*	28	½″ϕ	4′– 2″
	e	54	¼″□	9′– 2″		*e*	54	¼″□	9′– 8″
	f	54	¼″□	8′– 8″		*f*	57	¼″□	8′– 8″
	g	33	½″ϕ	17′– 6″		*g*	33	½″ϕ	18′– 6″
	h	18	¼″□	14′– 6″		*h*	18	¼″□	15′– 6″
17	*a*	27	½″ϕ	35′– 7″	18	*a*	28	½″ϕ	35′– 7″
	b	52	½″ϕ	32′–11″		*b*	56	½″ϕ	32′–11″
	c	10	½″ϕ	20′– 2″		*c*	10	½″ϕ	21′– 2″
	d	30	½″ϕ	4′– 2″		*d*	30	½″ϕ	4′– 2″
	e	54	¼″□	10′– 2″		*e*	54	¼″□	10′– 8″
	f	60	¼″□	8′– 8″		*f*	63	¼″□	8′– 8″
	g	33	½″ϕ	19′– 6″		*g*	33	½″ϕ	20′– 6″
	h	36	¼″□	8′– 8″		*h*	36	¼″□	9′– 2″
19	*a*	30	½″ϕ	35′– 7″	20	*a*	31	½″ϕ	35′– 7″
	b	58	½″ϕ	32′–11″		*b*	62	½″ϕ	32′–11″
	c	10	½″ϕ	22′– 2″		*c*	10	½″ϕ	23′– 2″
	d	32	½″ϕ	4′– 2″		*d*	34	½″ϕ	4′– 2″
	e	54	¼″□	11′– 2″		*e*	54	¼″□	11′– 8″
	f	66	¼″□	8′– 8″		*f*	69	¼″□	8′– 8″
	g	33	½″ϕ	21′– 6″		*g*	33	½″ϕ	22′– 6″
	h	36	¼″□	9′– 8″		*h*	36	¼″□	10′– 2″
21	*a*	33	½″ϕ	35′– 7″	22	*a*	34	½″ϕ	35′– 7″
	b	64	½″ϕ	32′–11″		*b*	68	½″ϕ	32′–11″
	c	10	½″ϕ	24′– 2″		*c*	10	½″ϕ	25′– 2″
	d	34	½″ϕ	4′– 2″		*d*	36	½″ϕ	4′– 2″
	e	54	¼″□	12′– 2″		*e*	54	¼″□	12′– 8″
	f	72	¼″□	8′– 8″		*f*	75	¼″□	8′– 8″
	g	33	½″ϕ	23′– 6″		*g*	33	½″ϕ	24′– 6″
	h	36	¼″□	10′– 8″		*h*	36	¼″□	11′– 2″
23	*a*	36	½″ϕ	35′– 7″	24	*a*	37	½″ϕ	35′– 7″
	b	70	½″ϕ	32′–11″		*b*	74	½″ϕ	32′–11″
	c	10	½″ϕ	26′– 8″		*c*	10	½″ϕ	27′– 8″
	d	38	½″ϕ	4′– 2″		*d*	38	½″ϕ	4′– 2″
	e	54	¼″□	13′– 2″		*e*	54	¼″□	13′– 8″
	f	78	¼″□	8′– 8″		*f*	81	¼″□	8′– 8″
	g	33	½″ϕ	25′– 6″		*g*	33	½″ϕ	26′– 6″
	h	36	¼″□	11′– 8″		*h*	36	¼″□	12′– 2″

a. Bent transverse bars—slab.
b. Straight transverse bars—slab.
c. Straight longitudinal bars in parapet and curb
d. Straight vertical bars in parapet and curb.
e. Straight longitudinal bars bar mat reinforcement.
f. Straight transverse bars bar mat reinforcement.
g. Straight longitudinal bars slab—top and bottom.
h. Straight longitudinal bars under I-beams.

FIG. 75.—(*Continued*)

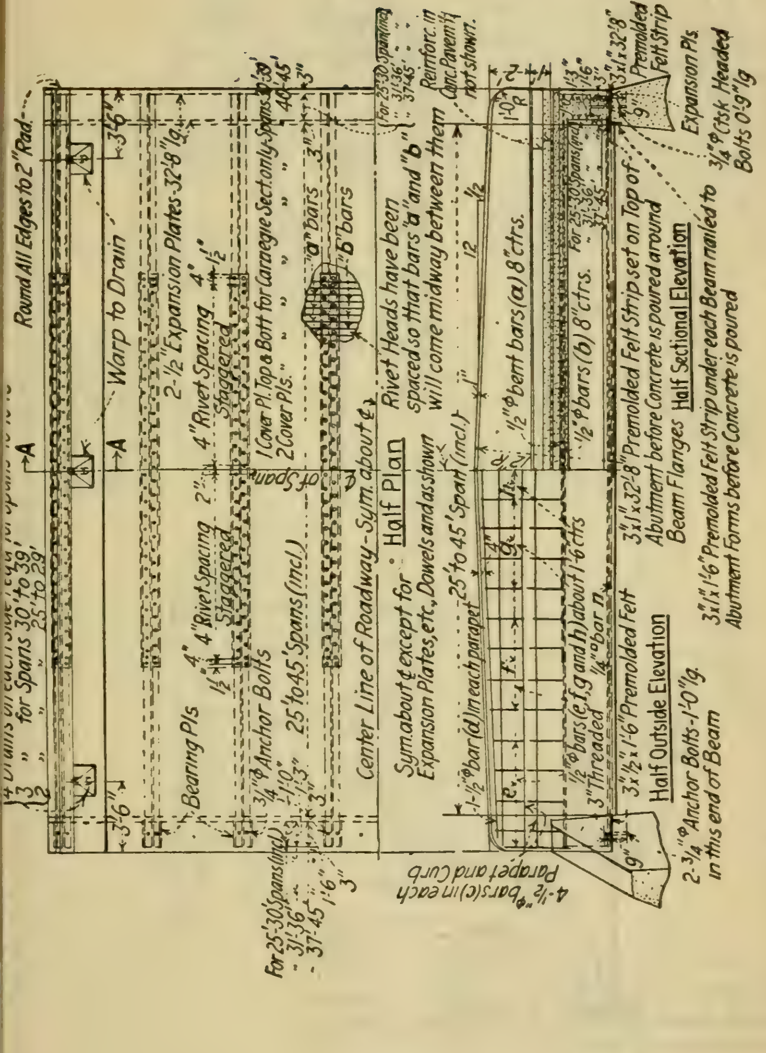


FIG. 76A.—Steel I beam superstructures (H-20 loading). Spans 25 to 45 feet. New York State Standards 1926. (Dimensions pages 278–283.)

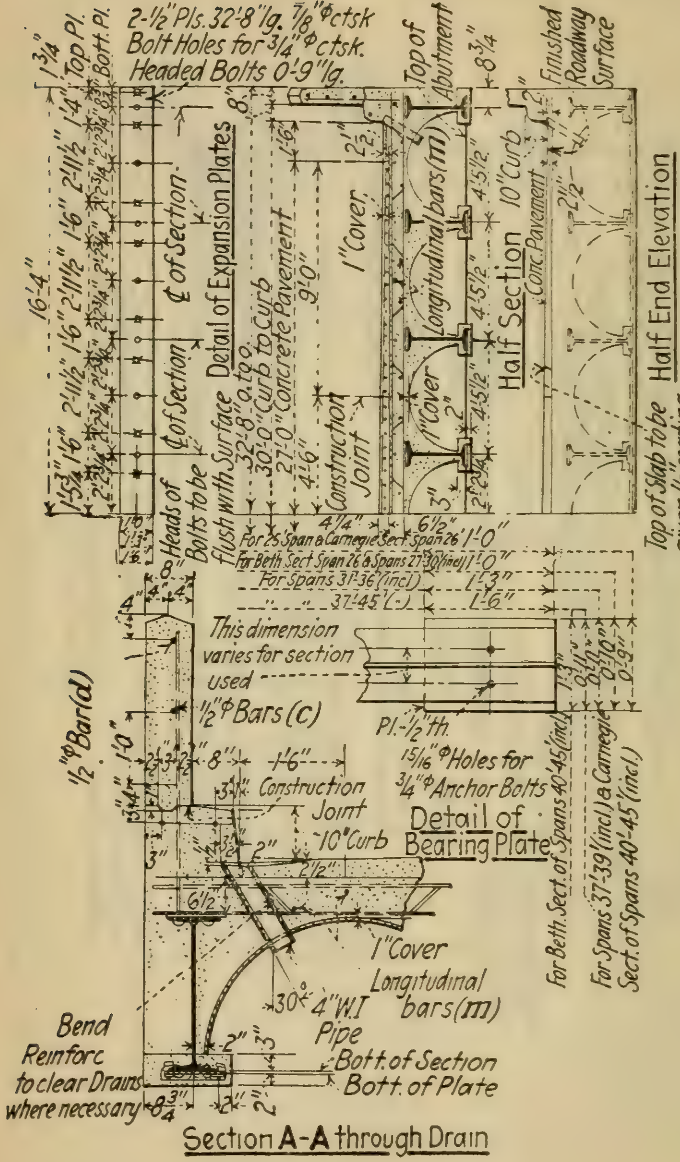


FIG. 76A.—(Continued.)

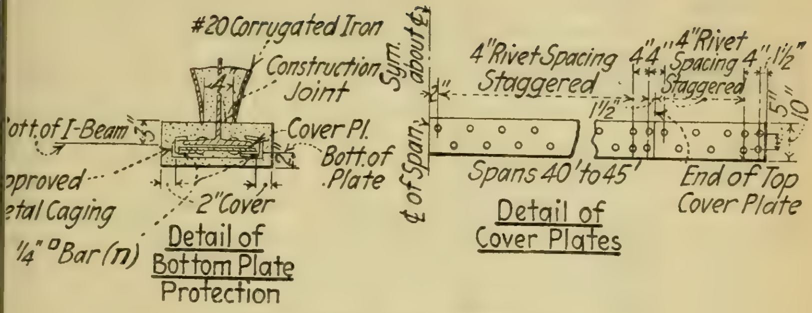
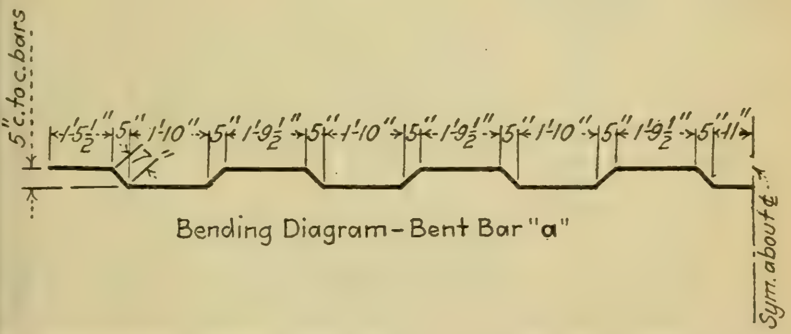


FIG. 76A.—(Continued.)



IG. 76A (Cont.).—Bar bending diagram. Floor slab. I-beam stringer bridge. 30 ft. roadway.

Clear span, ft.	I-beams					Summary of quantities required (no overrun or rounding)							
						Item No. 17	Item No. 51-D	Item No. 16	Item No. 15	Item No. 60-A	Item No. 30	Item No. 32-B	Item No. 32-A
	Section modulus required	Size	Type	No. required	Length	Cu. yds. concrete parapet	Cu. yds. concrete pavement	Cu. yds. concrete for structures	Bbls. Portland cement	Sq. ft. waterproofing	Sq. yds. reinforcement for pavement	Lbs. structural steel	Lbs. reinforcement for structures
25	172.0	24″–79.9#	Carnegie	8	27′– 6″	3.2	7.9	51.0	108¾	768	86.6	19,130	3,440
	172.0	24″–73.5#	Beth.	8	27′– 6″	3.2	7.9	51.4	109½	768	86.6	17,720	3,440
26	182.5	24″–90#	Carnegie	8	28′– 6″	3.3	8.2	52.7	112½	795	89.5	22,070	3,590
	182.5	24 3/32″–79.5#	Beth.	8	28′– 6″	3.3	8.2	53.5	113¾	795	89.5	19,690	3,590
27	195.0	27″–90#	Carnegie	8	29′– 6″	3.4	8.4	57.0	120½	823	92.5	22,800	3,710
	194.0	24″–84.5#	Beth.	8	29′– 6″	3.4	8.4	55.0	117	823	92.5	21,510	3,710
28	206.2	27″–90#	Carnegie	8	30′– 6″	3.5	8.7	58.7	124	850	95.4	23,530	3,850
	205.0	25⅞″–85.5#	Beth.	8	30′– 6″	3.5	8.7	58.1	123	850	95.4	22,430	3,850
29	217.0	27″–90#	Carnegie	8	31′– 6″	3.7	9.0	60.4	127¾	877	98.2	24,240	3,970
	216.2	26″–91#	Beth.	8	31′– 6″	3.7	9.0	60.2	127¼	877	98.2	24,500	3,970
30	233.0	27″–90# 2–10″ × ⅜ Pls.	Carnegie	8	32′– 6″ 9′–11″	3.8	9.3	63.1	133	905	101.1	27,120	4,120
	229.0	24″–99.5#	Beth.	8	32′– 6″	3.8	9.3	60.2	128	905	101.1	27,430	4,120

31	243.5	26⅛″–98#	Beth.	8	34′– 0″	4.0	9.8	65.3	138¼	946	105.4	28,610	4,250
32	260.0	27″–90# 2–10″ × ⅜ Pls.	Carnegie	8	35′– 0″ 15′–3″	4.1	10.0	68.4	144¼	973	108.3	30,470	4,400
	258.0	27⅞″–100#	Beth.	8	35′– 0″	4.1	10.0	68.5	144¼	973	108.3	29,950	4,400
33	272.5	27″–90# 2–10″ × ⅜ Pls.	Carnegie	8	36′– 0″ 17′– 3″	4.3	10.3	70.2	148¼	1,001	111.1	31,620	4,520
	272.0	28″–106#	Beth.	8	36′– 0″	4.3	10.3	70.5	148½	1,001	111.1	32,480	4,520
34	285.5	27″–90# 2–10″ × ⅜ Pls.	Carnegie	8	37′– 0″ 19′– 3″	4.4	10.6	72.0	152	1,028	114.1	32,770	4,670
	284.0	28″–106#	Beth.	8	37′– 0″	4.4	10.6	72.2	152¼	1,028	114.1	33,330	4,670
35	298.0	27″–90# 2–10″ × 7⁄16 Pls.	Carnegie	8	38′– 0″ 21′– 3″	4.6	10.0	73.7	155½	1,056	117.0	34,650	4,780
	298.0	28⅛″ × 113#	Beth.	8	38′– 0″	4.6	10.0	74.0	156	1,056	117.0	36,310	4,780
36	313.0	27″–90# 2–10″ × ½″ Pls.	Carnegie	8	39′– 0″ 22′– 7″	4.7	11.1	75.7	159¾	1,083	120.0	36,460	4,930
	312.0	29⅞″–115#	Beth.	8	39′– 0″	4.7	11.1	77.3	162½	1,083	120.0	36,830	4,930
37	331.0	27″–90# 2–10″ × 9⁄16 Pls.	Carnegie	8	40′– 6″ 23′–11″	4.9	11.5	79.3	167¼	1,124	127.7	39,120	5,070
	330.0	30″–121#	Beth.	8	40′– 6″	4.9	11.5	81.2	170½	1,124	127.7	41,540	5,070
38	344.5	27″–90# 2–10″ × ⅝ Pls.	Carnegie	8	41′– 6″ 25′–11″	5.0	11.8	81.4	171½	1,152	130.5	41,350	5,210
	344.0	30″–121#	Beth.	8	41′– 6″	5.0	11.8	83.0	174¼	1,152	130.5	42,500	5,210

FIG. 76A.—(*Continued.*)

Clear span, ft.	I-beams					Summary of quantities required (no overrun or rounding)							
						Item No. 17	Item No. 51-D	Item No. 16	Item No. 15	Item No. 60-A	Item No. 30	Item No. 32-B	Item No. 32-A
	Section modulus required	Size	Type	No. required	Length	Cu. yds. concrete parapet	Cu. yds. concrete pavement	Cu. yds. concrete for structures	Bbls. portland cement	Sq. ft. waterproofing	Sq. yds. reinforcement for pavement	Lbs. structural steel	Lbs. reinforcement for structures
39	360.0	27″–90# 2–10″ × 11/16 Pls.	Carnegie	8	42′– 6″ 27′– 3″	5.2	12.1	83.2	175¾	1,180	133.4	43,480	5,330
	359.0	30⅛″–129#	Beth.	8	42′– 6″	5.2	12.1	84.9	178½	1,180	133.4	46,190	5,330
40	374.0	27″–90# 2–10″ × ⅜″ Pls. 2–10″ × ⅜ Pls.	Carnegie	8	43′– 6″ 28′– 7″ 25′– 3″	5.3	12.4	85.4	180	1,207	136.2	45,010	5,470
	376.0	25⅞″–144#	Beth.	8	43′– 6″	5.3	12.4	83.9	177½	1,207	136.2	52,520	5,470
41	389.0	27″–90# 2–10″ × 7/16 Pls. 2–10″ × ⅜″ Pls.	Carnegie	8	44′–6″ 29′–11″ 25′– 3″	5.5	12.6	87.0	183¾	1,234	139.0	47,040	5,600
	393.0	26″–151#	Beth.	8	44′– 6″	5.5	12.6	86.[illegible]	182¼	1,234	139.0	56,170	5,600
42	406.0	27″–90# 2–10″ × 7/16″ Pls. 2–10″ × 7/16″ Pls.	Carnegie	8	45′– 6″ 31′–11″ 27′– 3″	5.6	13.0	89.1	188	1,261	142.0	49,600	5,740
	408.0	26″–151#	Beth.	8	45′– 6″	5.6	13.0	83.3	178¼	1,261	142.0	57,380	5,740

43	421.0	2–10″ × 7/16 Pls. 2–10″ × 1/2 Pls.	Carnegie	8	27′– 3″ 33′–3″	5.8	13.2	91.1	192 1/4	1,289	144.8	51,780	5,860
	424.0	26 1/8″–160#	Beth.	8	46′– 6″	5.8	13.2	90.1	190 1/4	1,289	144.8	61,930	5,860
44	439.0	27″–90# 2–10″ × 1/2″ Pls. 2–10″ × 1/2″ Pls.	Carnegie	8	47′– 6″ 33′–11″ 27′–11″	5.9	13.5	93.3	196 3/4	1,316	147.8	53,790	6,010
	444.0	28″–165#	Beth.	8	47′– 6″	5.9	13.5	93.4	196 3/4	1,316	147.8	65,110	6,010
45	452.0	27″–90# 2–10″ × 9/16 Pls. 2–10″ × 1/2″ Pls.	Carnegie	8	48′– 6″ 35′–11″ 27′–11″	6.1	13.8	95.1	201.0	1,344	150.7	56,290	6,120
	460.0	28″–165#	Beth.	8	48′– 6″	6.1	13.8	95.2	201 1/4	1,344	150.7	66,430	6,120

NOTES

The bar list shown makes no provision for splicing reinforcing bars except longitudinal 1/4″ □ bar ("n"). Bars may be spliced at places approved by the Engineer. Bars so spliced shall be lapped 40 diameters.

Concrete for pavement shall be 1: 1 1/2: 3 mix, all other concrete 1: 2: 3 1/2 mix.

The concrete used for encasement of bottom flanges of L's shall be made of stone not to exceed 3/4″ in size.

No construction joints other than those shown on the plans will be permitted without written permission of the Engineer. Construction joints to be free from laitance.

A layer of graphite grease about 1/8″ thick shall be placed between the expansion plates.

All reinforcing bars and structural steel shall be of medium open hearth steel. All dimensions for bending reinforcing bars are center to center of bars.

All parapet, fascia and curb surfaces shall be given a carborundum rubbed finish, cost to be included in the unit price for Items No. 16 and No. 17.

The cost of furnishing and installing pipe drains, metal caging, corrugated iron and premoulded felt strips shall be included in the unit price for Item No. 16.

All rivets shall be 3/4″ϕ.

The lower expansion plate shall be placed on top of abutment before concrete in abutment has set.

For name plate—see specifications.

Place 2-5/8″ϕ eyebolts, 1′–6″ long in each end of each parapet as directed by the Engineer for the attachment of cable guide railing. Cost of furnishing and placing to be included in the unit price for Item No. 17.

FIG. 76A.—*(Continued.)*

Bar list

Clear span, ft.	Mark	Size	No.	Length	Clear span, ft.	Mark	Size	No.	Length	Clear span, ft.	Mark	Size	No.	Length
25	*a*	½″φ	39	34′-8″	28	*a*	½″φ	43	34′-8″	31	*a*	½″φ	48	34′-8″
	b	½″φ	76	32′-4″		*b*	½″φ	86	32′-4″		*b*	½″φ	94	32′-4″
	c	½″φ	8	27′-8″		*c*	½″φ	8	30′-8″		*c*	½″φ	8	34′-2″
	d	½″φ	2	27′-0″		*d*	½″φ	2	30′-0″		*d*	½″φ	2	33′-6″
	e	½″φ	20	3′-3″		*e*	½″φ	20	3′-3″		*e*	½″φ	20	3′-3″
	f	½″φ	16	3′-6″		*f*	½″φ	16	3′-6″		*f*	½″φ	16	3′-6″
	g	½″φ	4	3′-9″		*g*	½″φ	8	3′-9″		*g*	½″φ	14	3′-9″
	m	½″φ	29	27′-6″		*m*	½″φ	29	30′-6″		*m*	½″φ	29	34′-0″
	n	¼″□	32	12′-8″		*n*	¼″□	32	14′-2″		*n*	¼″□	32	15′-8″
26	*a*	½″φ	40	34′-8″	29	*a*	½″φ	45	34′-8″	32	*a*	½″φ	49	34′-8″
	b	½″φ	80	32′-4″		*b*	½″φ	88	32′-4″		*b*	½″φ	98	32′-4″
	c	½″φ	8	28′-8″		*c*	½″φ	8	31′-8″		*c*	½″φ	8	35′-2″
	d	½″φ	2	28′-0″		*d*	½″φ	2	31′-0″		*d*	½″φ	2	34′-6″
	e	½″φ	20	3′-3″		*e*	½″φ	20	3′-3″		*e*	½″φ	20	3′-3″
	f	½″φ	16	3′-6″		*f*	½″φ	16	3′-6″		*f*	½″φ	16	3′-6″
	g	½″φ	6	3′-9″		*g*	½″φ	10	3′-9″		*g*	½″φ	14	3′-9″
	m	½″φ	29	28′-6″		*m*	½″φ	29	31′-6″		*m*	½″φ	29	35′-0″
	n	¼″□	32	13′-2″		*n*	¼″□	32	14′-8″		*n*	¼″□	48	11′-1″
27	*a*	½″φ	42	34′-8″	30	*a*	½″φ	46	34′-8″	33	*a*	½″φ	51	34′-8″
	b	½″φ	82	32′-4″		*b*	½″φ	92	32′-4″		*b*	½″φ	100	32′-4″
	c	½″φ	8	29′-8″		*c*	½″φ	8	32′-8″		*c*	½″φ	8	36′-2″
	d	½″φ	2	29′-0″		*d*	½″φ	2	32′-0″		*d*	½″φ	2	35′-6″
	e	½″φ	20	3′-3″		*e*	½″φ	20	3′-3″		*e*	½″φ	20	3′-3″
	f	½″φ	16	3′-6″		*f*	½″φ	16	3′-6″		*f*	½″φ	16	3′-6″
	g	½″φ	8	3′-9″		*g*	½″φ	12	3′-9″		*g*	½″φ	16	3′-9″
	m	½″φ	29	29′-6″		*m*	½″φ	29	32′-6″		*m*	½″φ	29	36′-0″
	n	¼″□	32	13′-8″		*n*	¼″□	32	15′-2″		*n*	¼″□	48	11′-5″

Clear span, ft.	Mark	Size	No.	Length	Clear span, ft.	Mark	Size	No.	Length	Clear span, ft.	Mark	Size	No.	Length	Clear span, ft.	Mark	Size	No.	Length
34	a	½″ φ	52	34′-8″	37	a	½″ φ	57	34′-8″	40	a	½″ φ	61	34′-8″	43	a	½″ φ	66	34′-8″
	b	½″ φ	104	32′-4″		b	½″ φ	112	32′-4″		b	½″ φ	122	32′-4″		b	½″ φ	130	32′-4″
	c	½″ φ	8	37′-2″		c	½″ φ	8	40′-8″		c	½″ φ	8	43′-8″		c	½″ φ	8	46′-8″
	d	½″ φ	2	36′-6″		d	½″ φ	2	40′-0″		d	½″ φ	2	43′-0″		d	½″ φ	2	46′-0″
	e	½″ φ	20	3′-3″		e	½″ φ	20	3′-3″		e	½″ φ	20	3′-3″		e	½″ φ	20	3′-3″
	f	½″ φ	16	3′-6″		f	½″ φ	16	3′-6″		f	½″ φ	16	3′-6″		f	½″ φ	16	3′-6″
	g	½″ φ	16	3′-9″		g	½″ φ	16	3′-9″		g	½″ φ	16	3′-9″		g	½″ φ	16	3′-9″
	h	½″ φ	2	4′-0″		h	½″ φ	6	4′-0″		h	½″ φ	10	4′-0″		h	½″ φ	14	4′-0″
	m	½″ φ	29	37′-0″		m	½″ φ	29	40′-6″		m	½″ φ	29	43′-6″		m	½″ φ	29	46′-6″
	n	¼″ □	48	11′-9″		n	¼″ □	48	12′-9″		n	¼″ □	48	13′-9″		n	¼″ □	48	14′-9″
35	a	½″ φ	54	34′-8″	38	a	½″ φ	58	34′-8″	41	a	½″ φ	63	34′-8″	44	a	½″ φ	67	34′-8″
	b	½″ φ	106	32′-4″		b	½″ φ	116	32′-4″		b	½″ φ	124	32′-4″		b	½″ φ	134	32′-4″
	c	½″ φ	8	38′-2″		c	½″ φ	8	41′-8″		c	½″ φ	8	44′-8″		c	½″ φ	8	47′-8″
	d	½″ φ	2	37′-6″		d	½″ φ	2	41′-0″		d	½″ φ	2	44′-0″		d	½″ φ	2	47′-0″
	e	½″ φ	20	3′-3″		e	½″ φ	20	3′-3″		e	½″ φ	20	3′-3″		e	½″ φ	20	3′-3″
	f	½″ φ	16	3′-6″		f	½″ φ	16	3′-6″		f	½″ φ	16	3′-6″		f	½″ φ	16	3′-6″
	g	½″ φ	16	3′-9″		g	½″ φ	16	3′-9″		g	½″ φ	16	3′-9″		g	½″ φ	16	3′-9″
	h	½″ φ	2	4′-0″		h	½″ φ	8	4′-0″		h	½″ φ	12	4′-0″		h	½″ φ	16	4′-0″
	m	½″ φ	29	38′-0″		m	½″ φ	29	41′-6″		m	½″ φ	29	44′-6″		m	½″ φ	29	47′-6″
	n	¼″ □	48	12′-1″		n	¼″ □	48	13′-1″		n	¼″ □	48	14′-1″		n	¼″ □	48	15′-1″
36	a	½″ φ	55	34′-8″	39	a	½″ φ	60	34′-8″	42	a	½″ φ	64	34′-8″	45	a	½″ φ	69	34′-8″
	b	½″ φ	110	32′-4″		b	½″ φ	118	32′-4″		b	½″ φ	128	32′-4″		b	½″ φ	136	32′-4″
	c	½″ φ	8	39′-2″		c	½″ φ	8	42′-8″		c	½″ φ	8	45′-8″		c	½″ φ	8	48′-8″
	d	½″ φ	2	38′-6″		d	½″ φ	2	42′-0″		d	½″ φ	2	45′-0″		d	½″ φ	2	48′-0″
	e	½″ φ	20	3′-3″		e	½″ φ	20	3′-3″		e	½″ φ	20	3′-3″		e	½″ φ	20	3′-3″
	f	½″ φ	16	3′-6″		f	½″ φ	16	3′-6″		f	½″ φ	16	3′-6″		f	½″ φ	16	3′-6″
	g	½″ φ	16	3′-9″		g	½″ φ	16	3′-9″		g	½″ φ	16	3′-9″		g	½″ φ	16	3′-9″
	h	½″ φ	4	4′-0″		h	½″ φ	8	4′-0″		h	½″ φ	12	4′-0″		h	½″ φ	16	4′-0″
	m	½″ φ	29	39′-0″		m	½″ φ	29	42′-6″		m	½″ φ	29	45′-6″		m	½″ φ	29	48′-6″
	n	¼″ □	48	12′-5″		n	¼″ □	48	13′-5″		n	¼″ □	48	14′-5″		n	¼″ □	48	15′-5″

a. Bent transverse bars—slab. *b.* Straight transverse bars—slab. *c.* Straight longitudinal bars in parapet and curb. *d.* Top longitudinal bar in parapet. *e.* Vertical bar in parapet and curb. *f.* Vertical bar in parapet and curb. *g.* Vertical bar in parapet and curb. *h.* Vertical bar in parapet and curb. *m.* Longitudinal bar in slab-top and bottom. *n.* Longitudinal bar under I-beams.

FIG. 76*A*.—(*Continued.*)

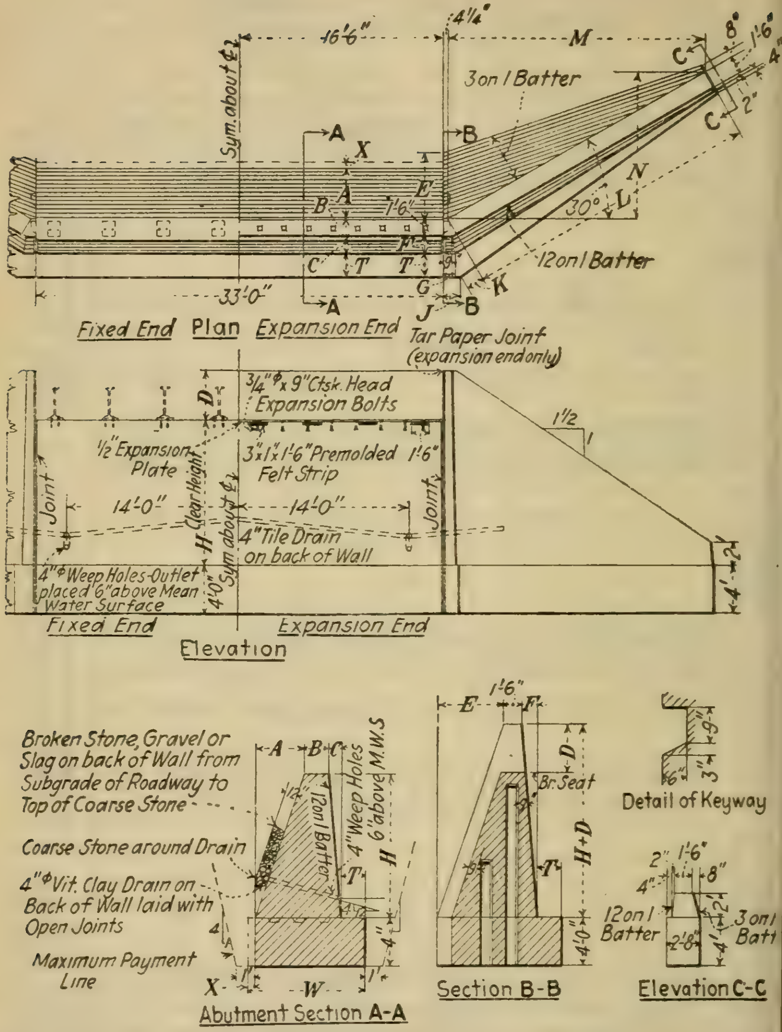
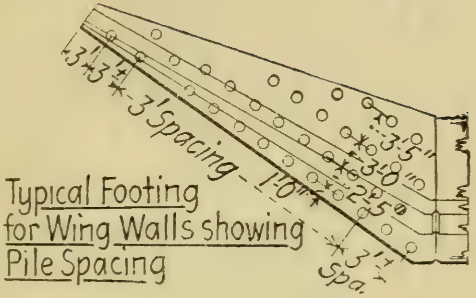


Fig. 76*B*.—Standard abutments steel I beam bridges. N. Y. Sta[te]
1926. (Dimesions and quantities pages 286–289.)

Note.—Design for ordinary foundation soils. Reduce base widt[h]
if gravel, hardpan or rock is encountered.



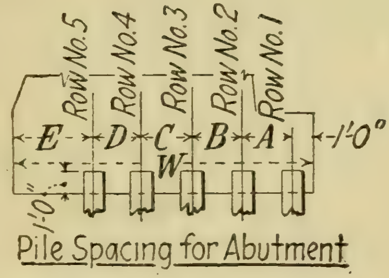


FIG. 76*B*.—(*Continued.*)

Clear span, feet	Clear height, H	Abutments							
		A	B	C	Footing W	Footing T	Footing X	Toe pressure, tons sq. ft.	Cu. yds. concrete 1–2½–5
25 to 30	8′	3′– 0″	1′–6″	0′– 8″	6′– 8″	1′– 6″	.....	2.2	65.2
	10′	3′–10″	1′–6″	0′–10″	7′– 9″	1′– 7″	.....	2.3	84.9
	12′	4′– 8″	1′–6″	1′– 0″	8′–10″	1′– 8″	.....	2.5	106.9
	14′	5′– 6″	1′–6″	1′– 2″	9′–11″	1′– 9″	.....	2.6	131.2
	16′	6′– 4″	1′–6″	1′– 4″	10′–11″	1′– 9″	.....	2.8	158.0
31 to 36	10′	3′– 5″	1′–9″	0′–10″	7′– 8″	1′– 8″	.....	2.6	84.8
	12′	4′– 3″	1′–9″	1′– 0″	8′– 9″	1′– 9″	.....	2.6	107.6
	14′	5′– 2″	1′–9″	1′– 2″	10′– 0″	1′–11″	.....	2.7	133.5
	16′	6′– 1″	1′–9″	1′– 4″	11′– 2″	2′– 0″	.....	2.9	164.0
	18′	7′– 0″	1′–9″	1′– 6″	12′– 3″	2′– 0″	.....	3.0	191.9
37 to 45	12′	4′– 0″	2′–0″	1′– 0″	9′– 0″	2′– 0″	.....	2.6	110.0
	14′	4′–10″	2′–0″	1′– 2″	10′– 2″	2′– 2″	.....	2.7	135.3
	16′	5′– 9″	2′–0″	1′– 4″	11′– 5″	2′– 4″	.....	2.8	164.3
	18′	6′– 8″	2′–0″	1′– 6″	12′– 9″	2′– 7″	.....	2.9	194.2
	20′	7′– 7″	2′–0″	1′– 8″	14′– 6″	2′– 9″	0′– 6″	2.7	230.3

FIG. 76*B*.—(*Continued.*)

Clear span, feet	Clear height, H	Wing walls										
		D	H + D	E	F	G	J	K	L	M	N	Cu. yds. concrete two wings
25 to 30	8′	2′–9½″	10′–9½″	3′– 7¼″	0′–10¾″	1′–0″	1′– 4″	0′–11¾″	15′– 2¾″	13′–2¼″	7′–7½″	47.6
	10′	2′–9½″	12′–9½″	4′– 3½″	1′– 0¾″	1′–0½″	1′– 5″	1′– 0¾″	18′– 8¼″	16′–2¼″	9′–4¼″	67.4
	12′	2′–9½″	14′–9½″	4′–11¾″	1′– 2¾″	1′–1″	1′– 5½″	1′– 1¼″	22′– 1¾″	19′–2¼″	11′–1″	92.4
	14′	2′–9½″	16′–9½″	5′– 8¼″	1′– 4¾″	1′–1½″	1′– 6¼″	1′– 2″	25′– 7½″	22′–2¼″	12′–9¾″	121.6
	16′	2′–9½″	18′–9½″	6′– 4½″	1′– 6¾″	1′–2″	1′– 6¾″	1′– 2½″	29′– 1″	25′–2¼″	14′–6½″	155.8
31 to 36	10′	3′–0″	13′–0″	4′– 4½″	1′– 1″	1′–0½″	1′– 5″	1′– 0¾″	19′– 0¾″	16′–6″	9′–6¼″	70.0
	12′	3′–0″	15′–0″	5′– 0¾″	1′– 3″	1′–1″	1′– 5¾″	1′– 1½″	22′– 6¼″	19′–6″	11′–3″	95.4
	14′	3′–0″	17′–0″	5′– 9″	1′– 5″	1′–1½″	1′– 6¾″	1′– 2½″	25′–11¾″	22′–6″	13′–0″	125.8
	16′	3′–0″	19′–0″	6′– 5½″	1′– 7″	1′–2″	1′– 7½″	1′– 3¼″	29′– 5¼″	25′–6″	14′–8¾″	161.2
	18′	3′–0″	21′–0″	7′– 1¾″	1′– 9″	1′–2½″	1′– 8″	1′– 3¾″	32′–11″	28′–6″	16′–5½″	202.4
37 to 45	12′	3′–0″	15′–0″	5′– 0¾″	1′– 3″	1′–1″	1′– 6½″	1′– 2¼″	22′– 6¼″	19′–6″	11′–3″	96.4
	14′	3′–0″	17′–0″	5′– 9″	1′– 5″	1′–1½″	1′– 7¼″	1′– 3″	25′–11¾″	22′–6″	13′–0″	126.8
	16′	3′–0″	19′–0″	6′– 5½″	1′– 7″	1′–2″	1′– 8¼″	1′– 4″	29′– 5¼″	25′–6″	14′–8¾″	163.0
	18′	3′–0″	21′–0″	7′– 1¾″	1′– 9″	1′–2½″	1′– 9½″	1′– 5¼″	32′–11″	28′–6″	16′–5½″	205.6
	20′	3′–0″	23′–0″	7′–10″	1′–11″	1′–3″	1′–10½″	1′– 6¼″	36′– 4½″	31′–6″	18′–2¼″	254.8

FIG. 76B.—(*Continued.*)

Span of bridge, feet	Clear height, H	Width of base, W	A	B	C	D	E	Longitudinal spacing					
								Row 1	Row 2	Row 3	Row 4	Row 5	
25 to 30	8′	6′– 8″	4′–0″	.....	.....	.....	1′– 8″	2′–6″	2′–6″				
	10′	7′– 9″	4′–0″	.....	.....	.....	2′– 9″	3′–0″	3′–0″				
	12′	8′–10″	4′–6″	.....	.....	.....	3′– 4″	2′–6″	2′–6″				
	14′	9′–11″	2′–6″	3′–6″	.....	.....	2′–11″	2′–6″	2′–6″	2′–6″			
	16′	10′–11″	2′–6″	5′–0″	.....	.....	2′– 5″	2′–6″	2′–6″	2′–6″			
31 to 36	10′	7′– 8″	4′–0″	.....	.....	.....	2′– 8″	2′–6″	2′–6″				
	12′	8′– 9″	2′–6″	2′–6″	.....	.....	2′– 9″	3′–0″	3′–0″	3′–0″			
	14′	10′– 0″	2′–6″	3′–6″	.....	.....	3′– 0″	2′–6″	2′–6″	2′–6″			
	16′	11′– 2″	2′–6″	5′–0″	.....	.....	2′– 8″	2′–6″	2′–6″	2′–6″			
	18′	12′– 3″	2′–6″	2′–6″	3′–6″	.....	2′– 9″	2′–6″	2′–6″	2′–6″	2′–6″		
37 to 45	12′	9′– 0″	2′–6″	2′–6″	.....	.....	3′–0″	3′–0″	3′–0″	3′–0″			
	14′	10′– 2″	2′–6″	3′–6″	.....	.....	3′– 2″	2′–6″	2′–6″	2′–6″			
	16′	11′– 5″	2′–6″	5′–0″	.....	.....	2′–11″	2′–6″	2′–6″	2′–6″			
	18′	12′– 9″	2′–6″	3′–0″	4′–0″	.....	2′–3″	2′–6″	2′–6″	2′–6″	2′–6″		
	20′	14′– 6″	2′–6″	2′–6″	2′–6″	2′– 6″	3′–6″	2′–6″	2′–6″	2′–6″	2′–6″	2′–6″	

FIG. 76*B*.—Table of pile spacing. (Diagram page 285).—(*Continued.*)

NOTES

The abutments and wing walls shown on this drawing are typical only. The engineer will give definite elevations and dimensions for each bridge.

The depth of footings shall be determined with respect to the character of the foundation material and the possibility of undermining. All footings shall rest on a firm foundation and except where rock is encountered, shall be at a depth at least four feet below the bed of stream or surface of ground.

The wing walls shall be designed and detailed to suit existing conditions and the angle between abutment and wing wall and the relative elevations of footings shall be made to fit the ground.

In case it appears that the soil will not safely withstand the unit pressure, noted in the above table of abutment dimensions, timber piles shall be used and spaced as shown in the table. These piles are designed for a maximum load of 15 tons. The tops of piles shall be placed below low water elevation and the estimated length of piles to be used shall be shown on the plans. In case excessive erosive action of the stream is expected, piles shall be used, rip-rap placed in front of the abutment or other approved means taken to prevent erosion.

Concrete in abutments and wing walls shall be 1–2½–5 mix., Item 21.

Keyways between abutments and wing walls and at all horizontal joints shall comprise about 30% of the area of surface.

All exposed edges of concrete shall be chamfered one inch.

The bases of structures shown on this sheet shall be considered as approximate only and may be ordered in writing by the Engineer to be at any elevation and of any dimensions necessary to give a proper foundation.

Payment for furnishing and placing dowels, expansion plates and bolts will be made at the respective contract prices for Metal Reinforcement and Structural Steel. (See superstructure details.)

Cost of furnishing and placing material in expansion joints at ends of bridge seat will be included in the price for Item 21.

Porous material placed on back of wall, will be paid for under Items 61, 62 and 63.

4″ vitrified clay drains on back of abutments will be paid for under Item 7.

FIG. 76*B*.—(*Continued.*)

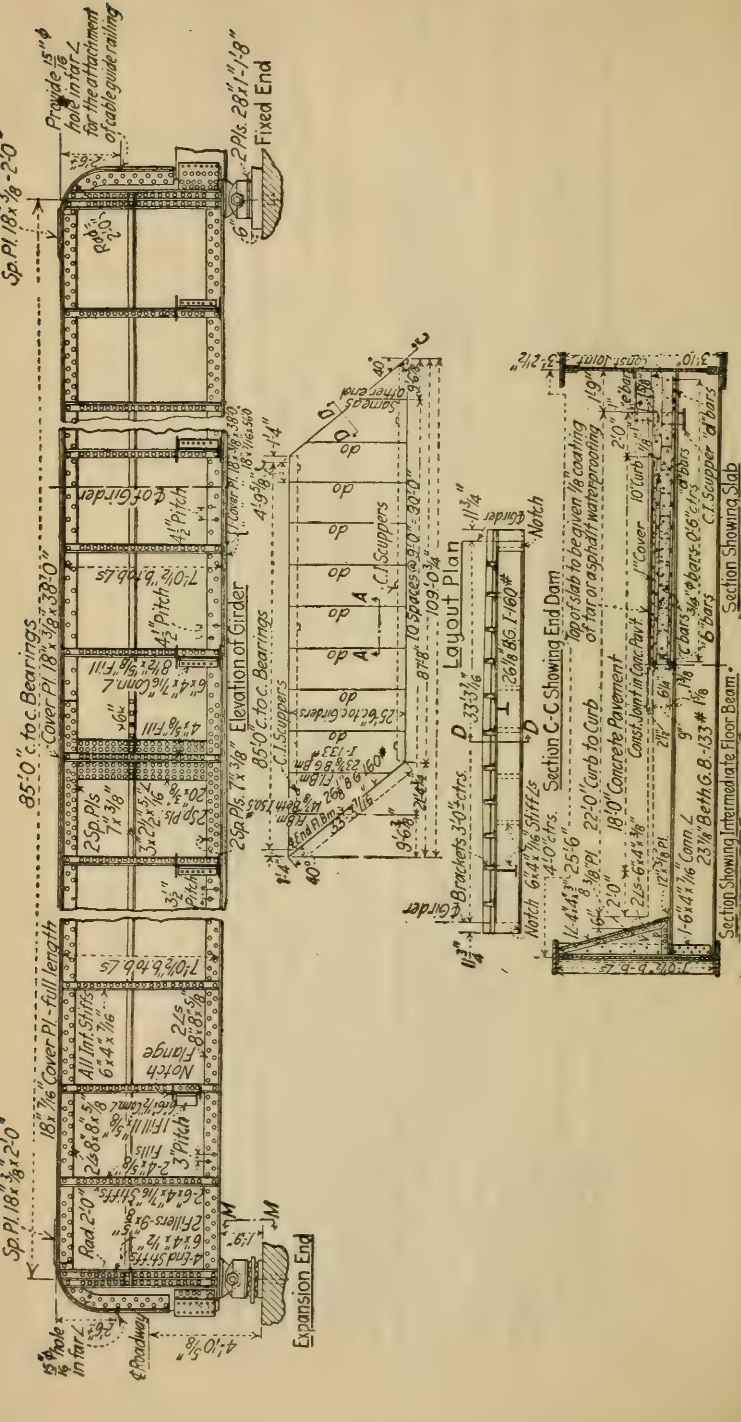


Fig. 77.—Typical plate girder. H-20 loading.

BAR LIST				
MARK	SIZE	NO.	LENGTH	
a	3/4"	88	29'-6"	Longitudinal Straight bars - Top and Bottom Slab
b	"	44	30'-9"	3'-3 · 6 1/4" · 3'-11 1/2" · 6 1/4" · 4'-0" · 6 1/4" · 1'-11 3/4" · Sym. about ℄ · 8 1/4 · Longitud Bent bars
c	"	42	25'-2"	Transverse Straight bars - Top and Bottom Slab 3"R 3"R.
d	"	48	9'-4"	Longitudinal Str. bars under Curb - hooked both ends
e	1/2"	4	29'-6"	Longitudinal bars in top of curb

NOTE: *This bar list applies to 6 intermediate panels only.*

FIG. 77.—(*Continued.*)

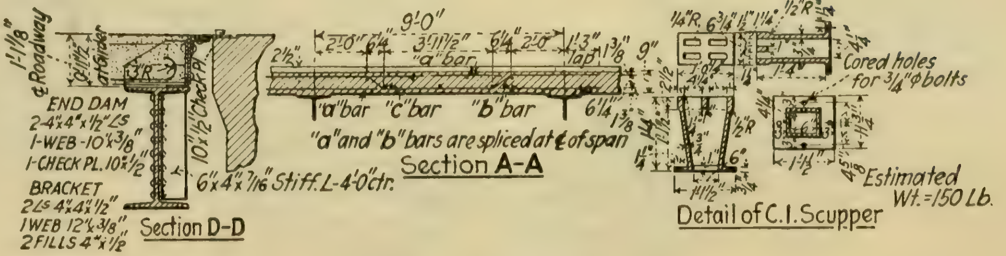


FIG. 77.—(*Continued.*)

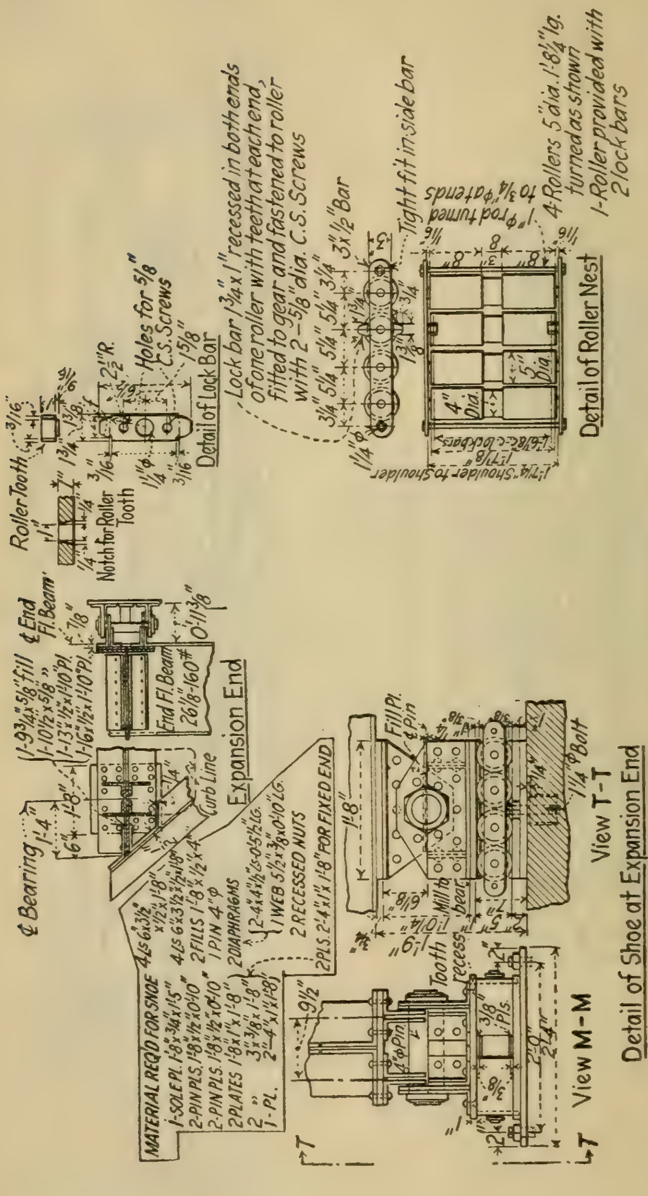


FIG. 77.—(*Continued.*)

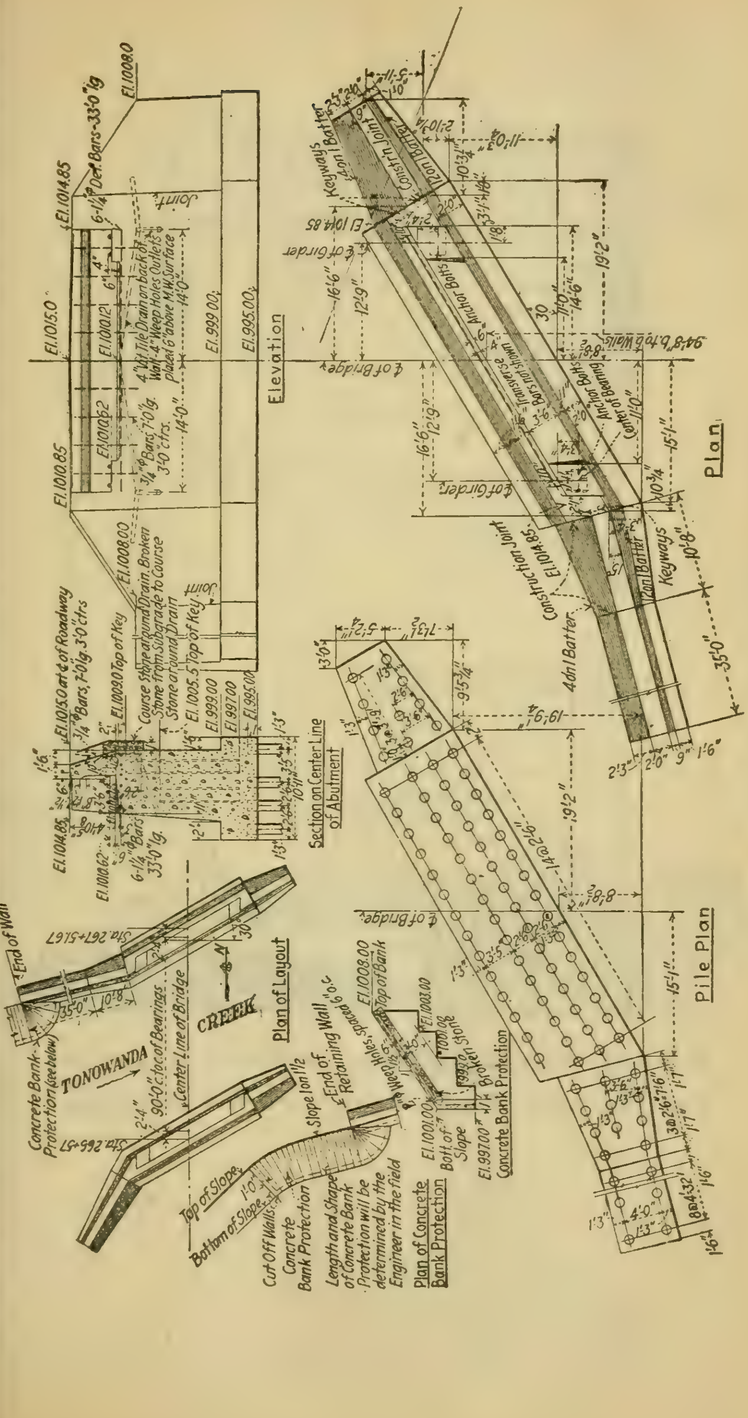
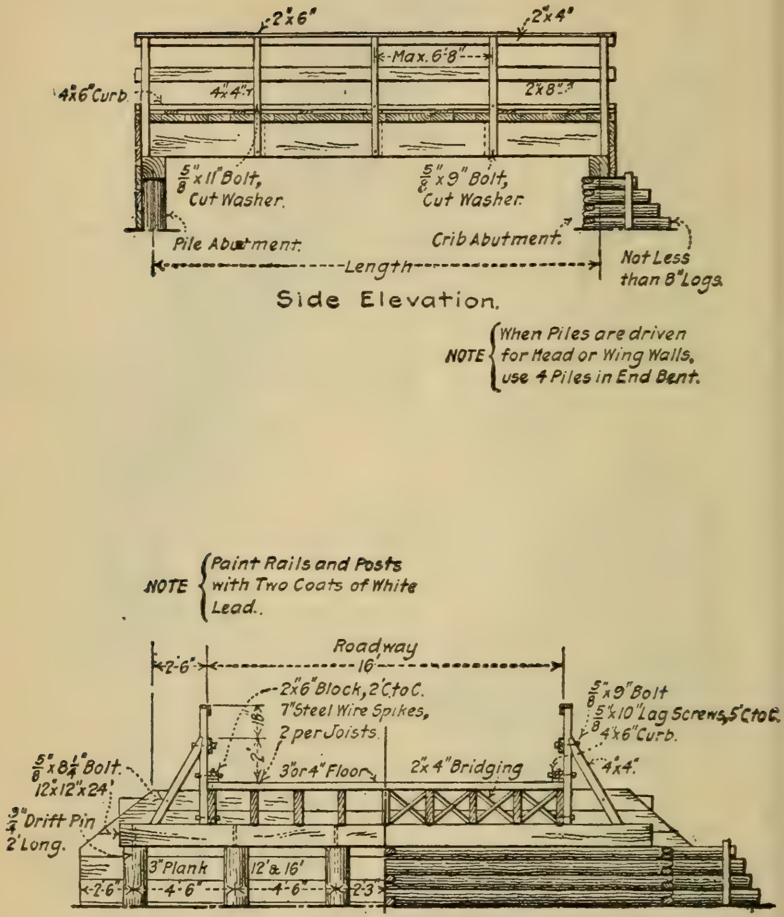


FIG. 78.—Typical plate girder abutment.



Half Section Pile Abutment. Half Section Crib Abutment.

FIG. 79.—Light wooden bridges. State of Wyoming.

Bill of Miscellaneous Material						
For Light Wooden Bridges 16′ to 25′ Long. 16′–18′–20′ Roadway. Capacity: 100# Per Sq. Foot + 25% Impact						
Name	Roadway	Maximum Spans of Joists				
		25′–0″ E. to E. 24′–0″ C. to C.	23′–0″ E. to E. 22′–0″ C. to C.	20′–0″ E. to E. 19′–0″ C. to C.	18′–0″ E. to E. 16′–9″ C. to C.	16′–0″ E. to E. 14′–6″ C. to C.
Bridging nails	Any	6#—10d	6#—10d	5#—10d	5#—10d	4#—10d
Rail nails	Any	6#—40d	6#—40d	5#—40d	5#—40d	4#—40d
Spikes for 4″ floor	16′	70#— 7″	65#— 7″	57#— 7″	51#— 7″	45#— 7″
Spikes for 4″ floor	18′	78#— 7″	72#— 7″	63#— 7″	57#— 7″	50#— 7″
Spikes for 4″ floor	20′	86#— 7″	80#— 7″	70#— 7″	62#— 7″	55#— 7″
Spikes for 3″ floor	16′	50#— 6″	45#— 6″	40#— 6″	55#— 6″	32#— 6″
Spikes for 3″ floor	18′	55#— 6″	50#— 6″	45#— 6″	40#— 6″	36#— 6″
Spikes for 3″ floor	20′	60#— 6″	58#— 6″	50#— 6″	45#— 6″	40#— 6″
Curb lag screws	Any	12—⅝″ × 10″	12—⅝″ × 10″	10—⅝″ × 10″	10—⅝″ × 10″	8—⅝″ × 10″
Rail bolts	Any	14—⅝″ × 9″	14—⅝″ × 9″	12—⅝″ × 9″	12—⅝″ × 9″	12—⅝″ × 9″
Rail bolts	Any	10—⅝″ × 11″	10—⅝″ × 11″	8—⅝″ × 11″	8—⅝″ × 11″	8—⅝″ × 11″
Rail bolts	Any	4—⅝″ × 8¼″	4—⅝″ × 8¼″	4—⅝″ × 8¼″	4—⅝″ × 8¼″	4—⅝″ × 8¼″
Pressed washers	Any	74 for ⅝″ bolts	74 for ⅝″ bolts	64 for ⅝″ bolts	64 for ⅝″ bolts	62 for ⅝″ bolts
All Nails and Spikes to be Steel Wire						

Fig. 79.—(*Continued.*)

Material for Pile Abutment

Name	Roadway	Quantity	Size	Length or Kind
Piling	16′–18′	6	12″ butt dia.	10′–0″ in ground
Cap	Any	1	12″ × 12″	24′–0″
Backing	Any	6 or more	3″ × 12″	12′–0″
Backing	Any	6 or more	3″ × 12″	16′–0″
Drifts	Any	6	¾″ φ	2′–0″
Nails for backing plk	Any	7½#	60d.	Steel wire nails

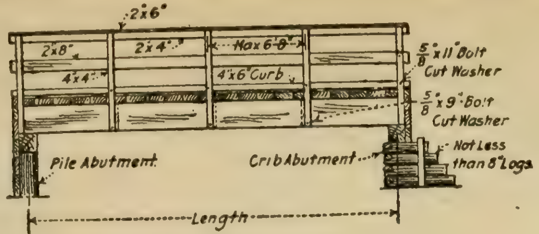
Maximum Length C. to C.	Roadway 16′–0″	Roadway 18′–0″	Roadway 20′–0″	Maximum Wheel Load Assumed on 2 Joists
24′–6″	9—4″ × 18″	10—4″ × 18″	11—4″ × 18″	3600#
22′–0″	9—4″ × 16″	10—4″ × 16″	11—4″ × 16″	5000#
19′–3″	9—4″ × 14″	10—4″ × 14″	11—4″ × 14″	4350#
16′–9″	9—4″ × 12″	10—4″ × 12″	11—4″ × 12″	3700#
19′–3″	9—3″ × 16″	10—3″ × 16″	11—3″ × 16″	4250#
16′–9″	9—3″ × 14″	10—3″ × 14″	11—3″ × 14″	3750#
14′–6″	9—3″ × 12″	10—3″ × 12″	11—3″ × 12″	3000#
Unit Load: 100# per sq. foot + 25% impact				Impact 25% allowed for

3″ × 12″ Floor (assumed worn to 2″) Good for 1600# Conc. Load
4″ × 12″ Floor (assumed worn to 3″) Good for 3600# Conc. Load

CAPACITY: 100# PER SQ. FOOT + 25% IMPACT

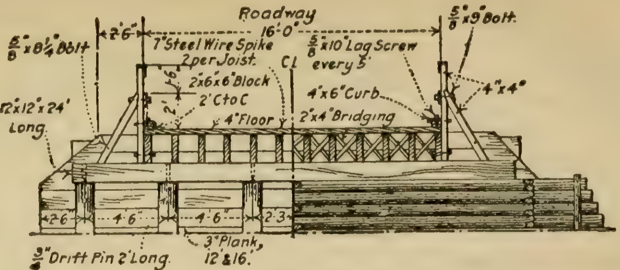
Name	Maximum Spans for Joists Shown				
	25′-0″ E. to E. 24′-0″ C. to C.	23′-0″ E. to E. C. to C.	20′-0″ E. to E. 19′-0″ C. to C.	18′-0″ E. to E. 16′-9″ C. to C.	16′-0″ E. to E. 14′-6″ C. to C.
			16′-0″ Roadway		
Joists	9—4″ × 18″ × 25′	9—4″ × 16″ × 23′	9—3″ × 16″ × 20′ or 9—4″ × 14″ × 20′	9—3″ × 14″ × 18′ or 9—4″ × 12″ × 18′	9—3″ × 12″ × 16′
Floor	27—3″ × 12″ × 16′ or 27—4″ × 12″ × 16′	25—3″ × 12″ × 16′ or 25—4″ × 12″ × 16′	22—3″ × 12″ × 16′ or 22—4″ × 12″ × 16′	20—3″ × 12″ × 16′ or 20—4″ × 12″ × 16′	18—3″ × 12″ × 16′ or 18—4″ × 12″ × 16′
Bridging	3—2″ × 4″ × 16′	3—2″ × 4″ × 16′	2—2″ × 4″ × 16′	2—2″ × 4″ × 16′	2—2″ × 4″ × 16′
			18′-0″ Roadway		
Joists	10—4″ × 18″ × 25′	10—4″ × 16″ × 23′	10—3″ × 16″ × 20′ or 10—4″ × 14″ × 20′	10—3″ × 14″ × 18′ or 10—4″ × 12″ × 18′	10—3″ × 12″ × 16′
Floor	27—3″ × 12″ × 18′ or 27—4″ × 12″ × 18′	25—3″ × 12″ × 18′ or 25—4″ × 12″ × 18′	22—3″ × 12″ × 18′ or 22—4″ × 12″ × 18′	20—3″ × 12″ × 18′ or 20—4″ × 12″ × 18′	18—3″ × 12″ × 16′ or 18—4″ × 12″ × 16′
Bridging	4—2″ × 4″ × 14′	4—2″ × 4″ × 14′	3—2″ × 4″ × 12′	3—2″ × 4″ × 12′	3—2″ × 4″ × 12′
			20′-0″ Roadway		
Joists	11—4″ × 18″ × 25′	11—4″ × 16″ × 23′	11—3″ × 16″ × 20′ or 11—4″ × 14″ × 20′	11—3″ × 14″ × 18′ or 11—4″ × 12″ × 18′	11—3″ × 12″ × 16′
Floor	27—3″ × 12″ × 20′ or 27—4″ × 12″ × 20′	25—3″ × 12″ × 20′ or 25—4″ × 12″ × 20′	22—3″ × 12″ × 20′ or 22—4″ × 12″ × 20′	20—3″ × 12″ × 20′ or 20—4″ × 12″ × 20′	18—3″ × 12″ × 20′ or 18—4″ × 12″ × 20′
Bridging	4—2″ × 4″ × 16′	4—2″ × 4″ × 16′	3—2″ × 4″ × 14′	3—2″ × 4″ × 14′	3—2″ × 4″ × 14′
			Any Roadway		
Curb	3—4″ × 6″ × 16′	3—4″ × 6″ × 16′	3—4″ × 6″ × 14′	2—4″ × 6″ × 18′	2—4″ × 6″ × 16′
Rail S.4S	5—4″ × 4″ × 16′ 4—2″ × 4″ × 14′ 4—2″ × 6″ × 14′ 4—2″ × 8″ × 14′	5—4″ × 4″ × 16′ 4—2″ × 4″ × 12′ 4—2″ × 6″ × 12′ 4—2″ × 8″ × 12′	4—4″ × 4″ × 16′ 2—2″ × 4″ × 20′ 2—2″ × 6″ × 20′ 2—2″ × 8″ × 20′	4—4″ × 4″ × 18′ 2—2″ × 4″ × 18′ 2—2″ × 6″ × 18′ 2—2″ × 8″ × 18′	4—4″ × 4″ × 16′ 2—2″ × 4″ × 16′ 2—2″ × 6″ × 16′ 2—2″ × 8″ × 16′
Blocks	27—2″ × 6″ × 6″	25—2″ × 6″ × 6″	22—2″ × 6″ × 6″	20—2″ × 6″ × 6″	18—2″ × 6″ × 6″

FIG. 79.—(*Continued.*)



Note.
Paint Rails and Posts with Two Coats of White Lead.

Side Elevation.



Half Section Pile Abutment. Half Section Crib Abutment

BILL OF MISCELLANEOUS MATERIAL

FOR STANDARD WOODEN BRIDGES 8' TO 20' LONG. 16'–18'–20' ROADWAY.
CAPACITY: 20-TON TRACTION ENG. (2/3 ON REAR AXLE) + 25% IMPACT

Name	Road-way	Maximum Spans of Joists				
		20'–0" E. to E. 19'–0" C. to C.	16'–0" E. to E. 15'–0" C. to C.	12'–0" E. to E. 11'–0" C. to C.	10'–0" E. to E. 9'–0" C. to C.	8'–0" E. to E. 7'–0" C. to C.
Bridging nails..........	Any	6#—10d	6#—10d	4#—10d	4#—10d	
Rail nails..............	Any	5#—40d	4#—40d	3#—40d	3#—40d	2#—40d
Floor spikes...........	16	80#— 7"	64#— 7"	48#— 7"	40#— 7"	32#— 7"
Floor spikes...........	18	80#— 7"	64#— 7"	48#— 7"	40#— 7"	32#— 7"
Floor spikes...........	20	88#— 7"	70#— 7"	53#— 7"	44#— 7"	35#— 7"
Curb lag screws........	Any	10—5/8"×10"	8—5/8"×10"	6—5/8"×10"	6—5/8"×10"	6—5/8"×10"
Rail bolts.............	Any	12—5/8"× 9"	12—5/8"× 9"	10—5/8"× 9"	10—5/8"× 9"	8—5/8"× 9"
Rail bolts.............	Any	8—5/8"×11"	8—5/8"×11"	6—5/8"×11"	6—5/8"×11"	4—5/8"×11"
Rail bolts.............	Any	4—5/8"×8 1/4"	4—5/8"×8 1/4"	4—5/8"×8 1/4"	4—5/8"×8 1/4"	4—5/8"×8 1/4"
Pressed washers........	Any	64 for 5/8" bolts	62 for 5/8" bolts	50 for 5/8" bolts	50 for 5/8" bolts	42 for 5/8" bolts

ALL NAILS AND SPIKES TO BE STEEL WIRE

Material for One Pile Abutment

Name	Roadway	Quantity	Size	Length or Kind
Piling	16′–18′	6	12″ butt dia.	10′–0″ in ground
Cap	Any	1	12″ × 12″	24′–0″
Backing	Any	6 or more	3″ × 12″	12′–0″
Backing	Any	6 or more	3″ × 12″	16′–0″
Drifts	Any	6	¾″ φ	2′–0″
Nails for backing plk	Any	7½#	60d	Steel wire nails

Maximum Length C. to C.	Roadway		
	16′–0″	18′–0″	20′–0″
20′–0″	12—4″ × 18″	12—4″ × 18″	14—4″ × 18″
16′–0″	12—4″ × 16″	12—4″ × 16″	14—4″ × 16″
12′–0″	12—4″ × 14″	12—4″ × 14″	14—4″ × 14″
11′–9″	12—3″ × 16″	12—3″ × 16″	14—3″ × 16″
9′–0″	12—3″ × 14″	12—3″ × 14″	14—3″ × 14″
8′–9″	12—4″ × 12″	12—4″ × 12″	14—4″ × 12″
6′–6″	12—3″ × 12″	12—3″ × 12″	14—3″ × 12″

Fig. 80.—(*Continued.*)

Bill of Lumber
For Standard Wooden Bridges 8′ to 20′ Long. 16′–18′–20′ Roadway.
Capacity: 20-ton Traction Eng. (⅔ on Rear Axle) + 25% Impact

Name	Maximum Spans for Joists Shown: 20′–0″ E. to E. 19′–0″ C. to C.	16′–0″ E. to E. 15′–0″ C. to C.	12′–0″ E. to E. 11′–0″ C. to C.	10′–0″ E. to E. 9′–0″ C. to C.	8′–0″ E. to E. 7′–0″ C. to C.
		16′–0″ Roadway			
Joists	12—4″×18″×20′	12—4″×16″×16′	12—3″×16″×12′ or 12—4″×14″×12′	12—3″×14″×10′ or 12—4″×12″×10′	12—3″×12″×8′
Floor	22—4″×12″×16′	18—4″×12″×16′	14—4″×12″×16′	11—4″×12″×16′	9—4″×12″×16′
Bridging	9—2″× 4″×16′	9—2″× 4″×16′	5—2″× 4″×16′	5—2″× 4″×16′	
		18′–0″ Roadway			
Joists	12—4″×18″×20′	12—4″×16″×16′	12—3″×16″×12′ or 12—4″×14″×12′	12—3″×14″×10′ or 12—4″×12″×10′	12—3″×12″× 8′
Floor	22—4″×12″×18′	18—4″×12″×18′	14—4″×12″×18′	11—4″×12″×18′	9—4″×12″×18′
Bridging	10—2″× 4″×16′	10—2″× 4″×16′	6—2″× 4″×16′	6—2″× 4″×16′	
		20′–0″ Roadway			
Joists	14—4″×18″×20′	14—4″×16″×16′	14—3″×16″×12′ or 14—4″×14″×12′	14—3″×14″×10′ or 14—4″×12″×10′	14—3″×12″× 8′
Floor	22—4″×12″×20′	18—4″×12″×20′	14—4″×12″×20′	11—4″×12″×20′	9—4″×12″×20′
Bridging	12—2″× 4″×16′	12—2″× 4″×16′	7—2″× 4″×16′	7—2″× 4″×16′	
		Any Roadway			
Curb	3—4″× 6″×14′	2—4″× 6″×16′	2—4″× 6″×12′	2—4″× 6″×10′	2—4″× 6″× 8′
Rail S. 4S.	4—4″× 4″×16′	4—4″× 4″×16′	3—4″× 4″×16′	3—4″× 4″×16′	2—4″× 4″×16′
	2—2″× 4″×20′	2—2″× 4″×16′	2—2″× 4″×12′	2—2″× 4″×10′	2—2″× 4″× 8′
	2—2″× 6″×20′	2—2″× 6″×16′	2—2″× 6″×12′	2—2″× 6″×10′	2—2″× 6″× 8′
	2—2″× 8″×20′	2—2″× 8″×16′	2—2″× 8″×12′	2—2″× 8″×10′	2—2″× 8″× 8′
Blocks	22—2″× 6″× 6″	18—2″× 6″× 6″	14—2″× 6″× 6″	12—2″× 6″× 6″	10—2″× 6″× 6″

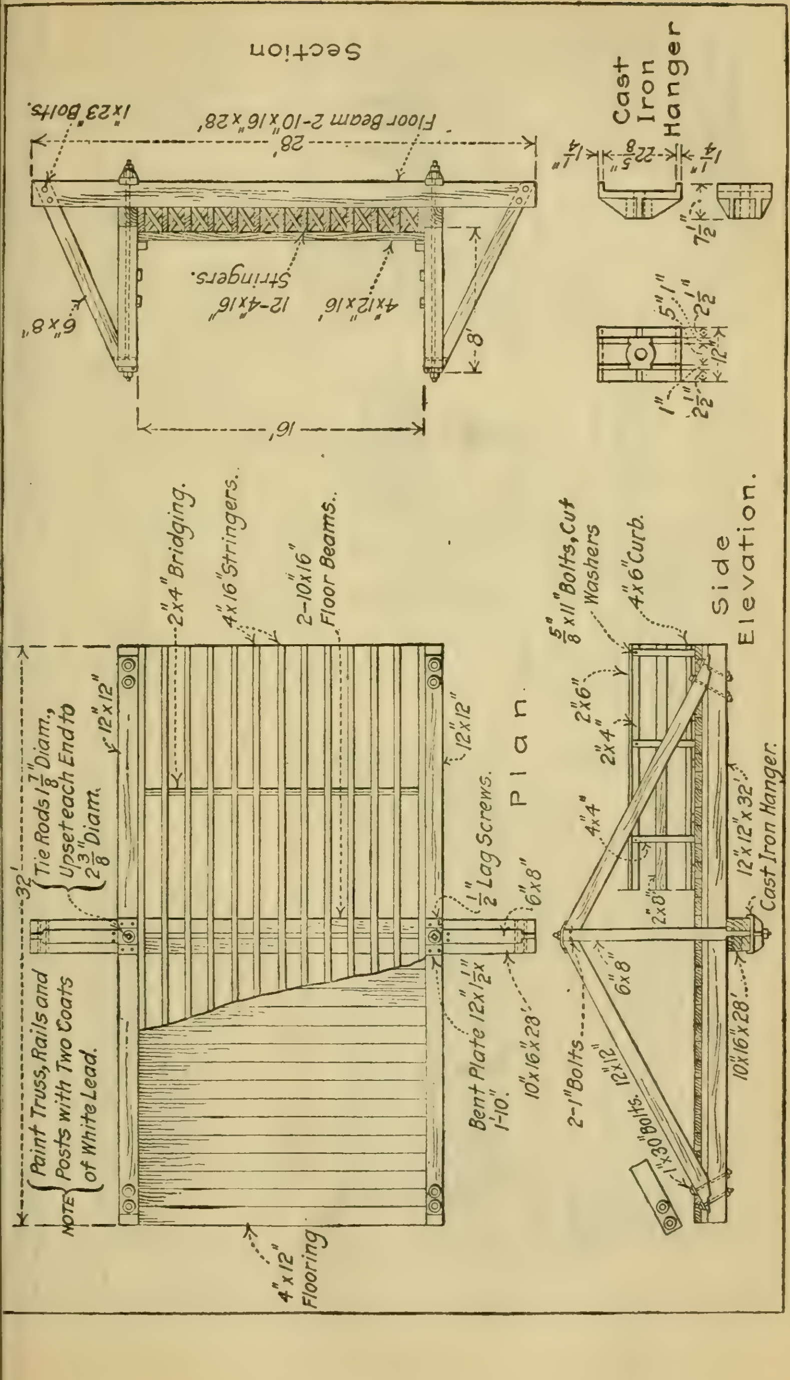


FIG. 81.—30′ span king post timber bridge. State of Wyoming.

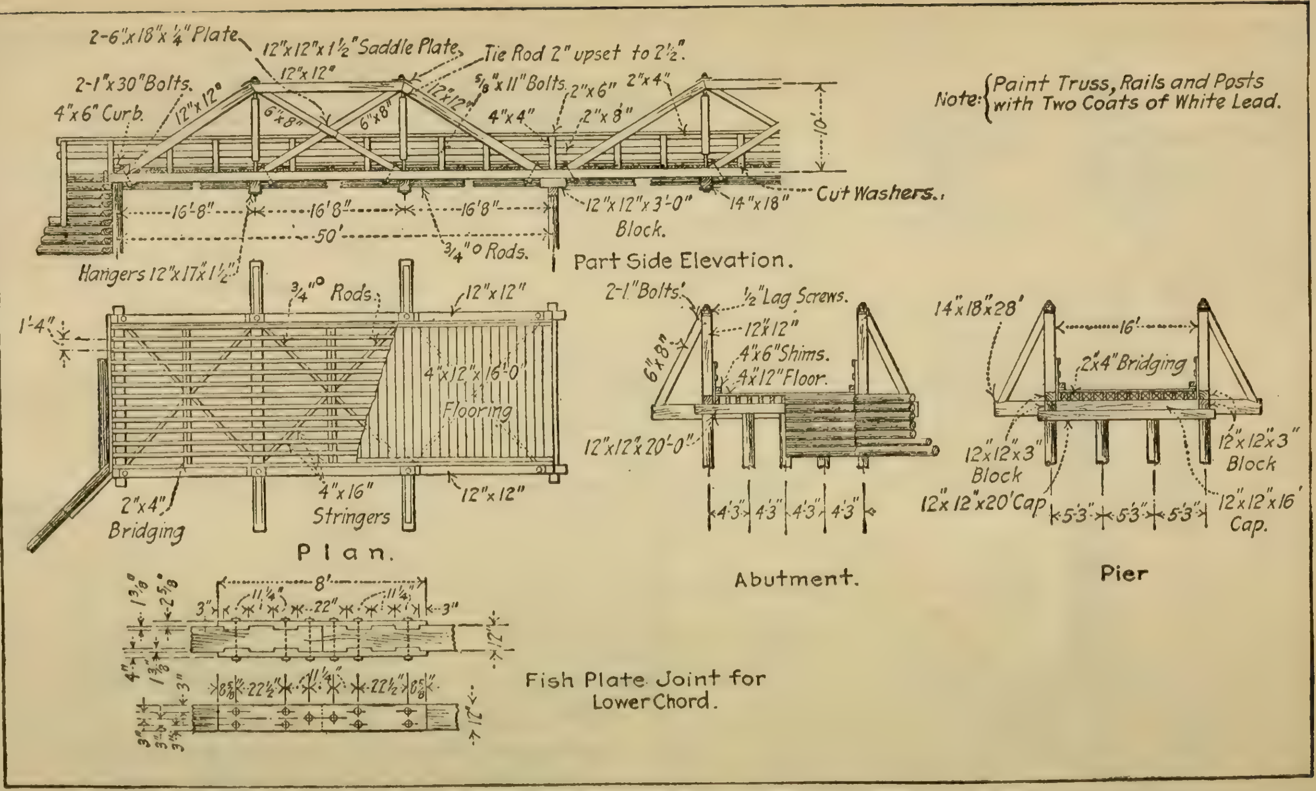


FIG. 82.—Typical 50′ span pony truss timber bridge. State of Wyoming.

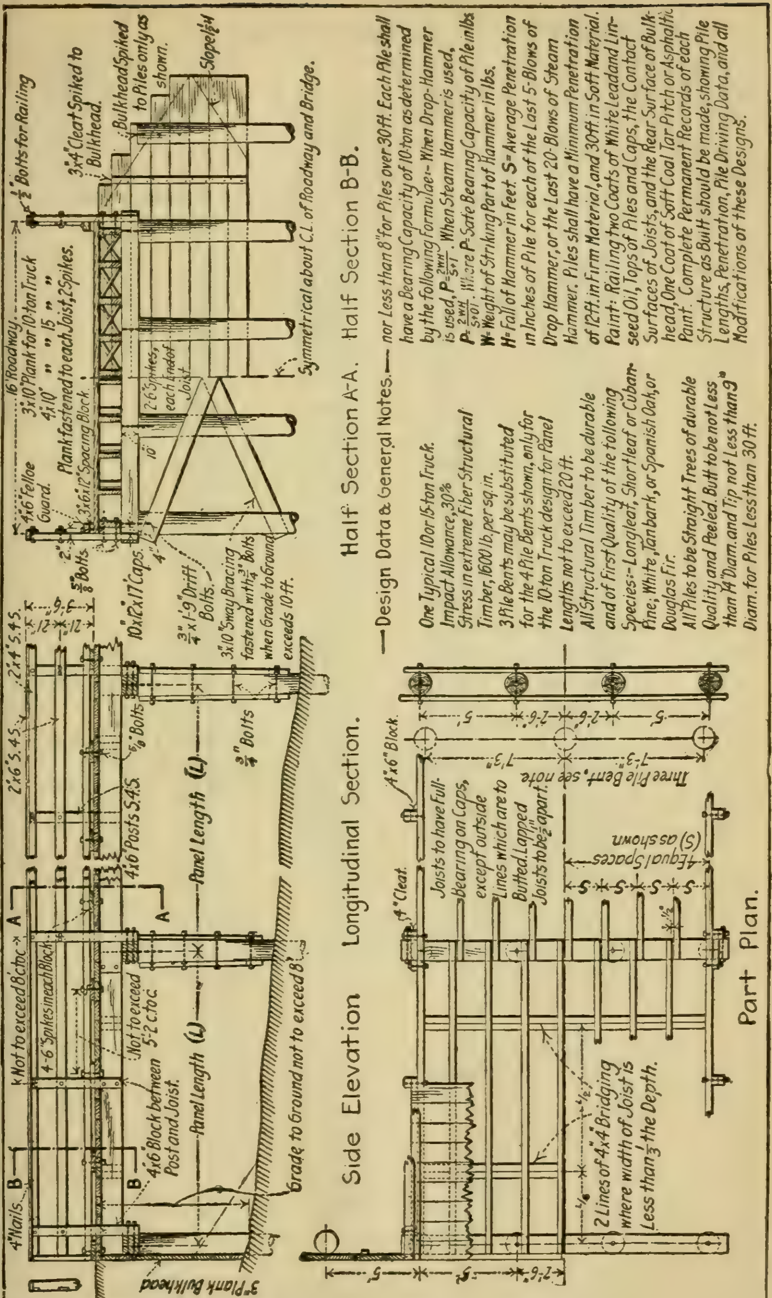


FIG. 83.—Typical pile trestle. U. S. office of public roads.

Panel Length (L)	Intermediate Panel				
	Size of Joists	Joists	Floor Railing Details	Total Lumber	Bolts, Washers, Spikes, Nails
Feet	Inches	Ft. B. M.	Ft. B. M.	Ft. B. M.	Pounds
10	6×12	590	800	1390	80
	4×14	460	840	1300	
11	6×12	650	870	1520	90
	4×14	500	920	1420	
12	6×12	700	940	1640	90
	4×16	620	990	1610	
	8×12	1010	1020	2030	
13	6×14	880	1020	1900	90
	4×16	670	1070	1740	
	8×12	1080	1090	2170	
14	6×14	950	1090	2040	90
	4×16	720	1140	1860	
15	8×12	1150	1170	2320	100
	6×14	1010	1170	2180	
16	10×12	1530	1240	2770	
	6×14	1070	1240	2310	100
	6×16	1230	1240	2470	
17	10×12	1620	1340	2960	
	8×14	1510	1340	2850	120
	6×16	1300	1340	2640	
18	10×12	1710	1410	3120	
	8×14	1600	1410	3010	130
	6×16	1370	1410	2780	
19	10×12	1800	1490	3290	
	8×14	1680	1490	3170	130
	6×16	1440	1490	2930	
20	8×14	1760	1560	3320	130
	8×16	2020	1560	3580	
21	10×14	2310	1640	3950	140
	8×16	2110	1640	3750	
22	10×14	2410	1710	4120	150
	8×16	2210	1710	3920	

FIG. 83.—(*Continued.*)

Panel Length (L)	Size of Joists	Intermediate Panel			
		Joists	Floor Railing Details	Total Lumber	Bolts, Washers, Spikes, Nails
Feet	Inches	Ft. B. M.	Ft. B. M.	Ft. B. M.	Pounds
10	4×12	400	640	1040	70
	3×14	350	680	1030	
11	4×12	430	700	1130	80
	3×14	380	740	1120	
12	6×12	700	760	1460	80
	3×14	410	800	1210	
13	6×12	760	810	1570	80
	4×14	590	860	1450	
14	6×12	810	870	1680	
	4×14	630	910	1540	90
	4×16	720	910	1630	
15	6×12	860	930	1790	
	4×14	670	970	1640	90
	4×16	770	970	1740	
16	6×12	920	990	1910	
	6×14	1070	990	2060	100
	4×16	820	1030	1850	
17	6×12	970	1070	2040	
	6×14	1130	1070	2200	110
	4×16	870	1110	1980	
18	8×12	1370	1130	2500	
	6×14	1200	1130	2330	120
	4×16	910	1170	2080	
19	8×12	1440	1180	2620	
	6×14	1260	1180	2440	120
	4×16	960	1220	2180	
20	8×12	1510	1240	2750	
	6×14	1320	1240	2560	120
	6×16	1510	1240	2750	
21	10×12	1980	1300	3280	
	6×14	1390	1300	2690	130
	6×16	1580	1300	2880	
22	10×12	2070	1360	3430	
	8×14	1930	1360	3290	130
	6×16	1660	1360	3020	
23	10×12	2160	1420	3580	
	8×14	2020	1420	3440	130
	6×16	1730	1420	3150	
24	10×12	2250	1470	3720	
	8×14	2100	1470	3570	130
	6×16	1800	1470	3270	
25	10×14	2730	1560	4290	
	8×14	2180	1560	3740	150
	6×16	1870	1560	3430	
26	10×14	2840	1610	4450	160
	8×16	2600	1610	4210	
27	10×14	2940	1670	4610	160
	8×16	2690	1670	4360	
28	10×14	3050	1730	4780	160
	8×16	2780	1730	4510	
29	10×14	3150	1790	4940	160
	8×16	2880	1790	4670	

Washers to be ogee type cast iron ⅝″ and ⅜″ bolts, and cut wrought iron or steel plate washers for ½″ bolts.

FIG. 83.—(*Continued.*)

Grade to Ground	Sway Bracing—Intermediate Bent			
	Sets	Length	Lumber	Bolts
Feet	No. Reqd.	Feet	Ft. B. M.	Pounds
10–12	1	18	90	35
12–15	1	20	100	35
15–18	1	22	110	35
18–23	2	18 & 20	190	60
23–26	2	20	200	60
One cap 10″×12″×17′–0″			170	10

Grade to Ground	Bulkhead—End Bent	
	Lumber	Spikes
Feet	Ft. B. M.	Pounds
4	270	5
5	360	5
6	460	10
7	550	10
8	640	10

FIG. 83.—(*Continued.*)

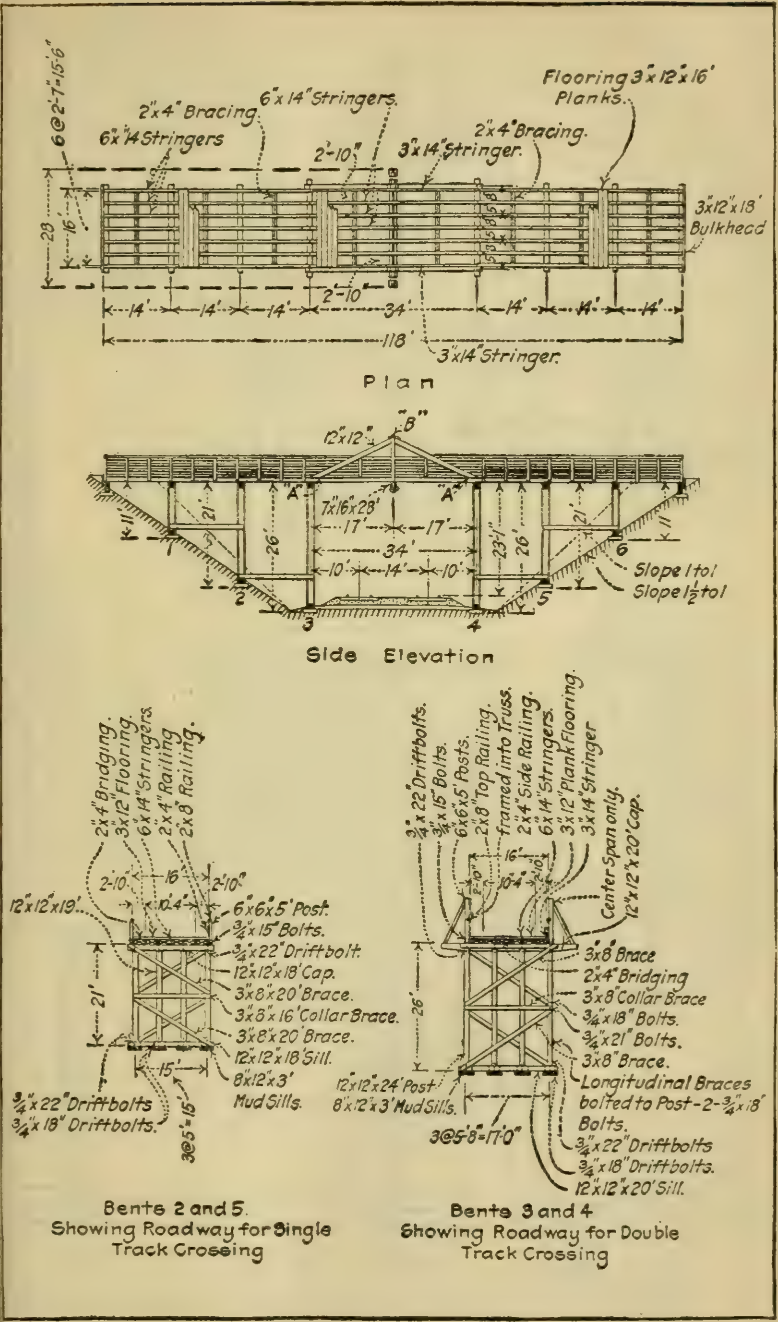
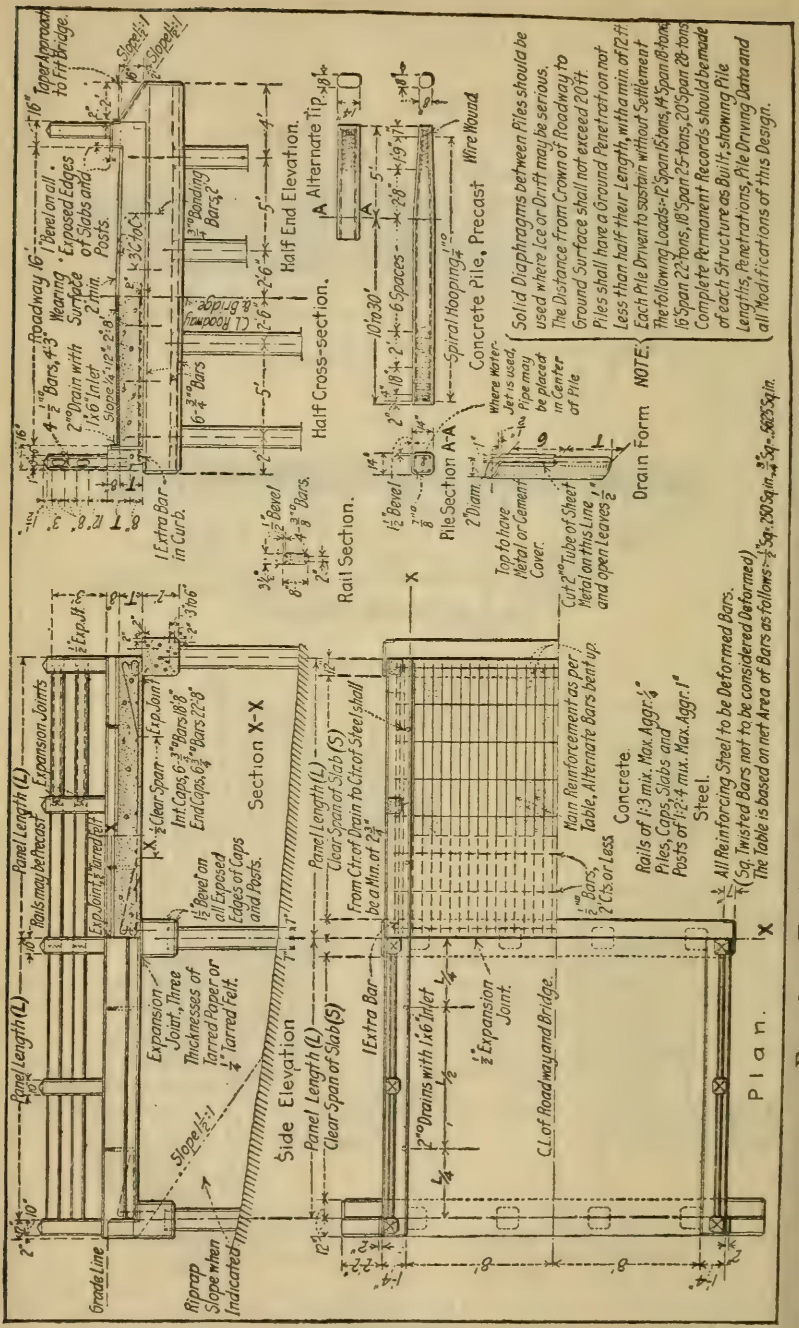


FIG. 84.—Typical framed trestle. Illinois Central Railroad.



Half Cross-section.
Half End Elevation.
Roadway 16'
Wearing Surface 2" min.
2" Drain with 1x6" Inlet Slope 1/4":12"=2.8"
1" Bevel on all Exposed Edges of Slabs and Posts.
Taper Approach to Fit Bridge.
CL Roadway & Bridge
1 Extra Bar in Curb.
Rail Section.
Alternate Tip
Pile Section A-A
Concrete Pile, Precast
Spiral Hooping 1/4"
Wire Wound
6 Spaces
10' to 30'
Where Water-Jet is used, Pipe may be placed in Center of Pile
Top to have Metal or Cement Cover.
Cut 2" Tube of Sheet Metal on this Line and open Leaves 1/2"
Drain Form
NOTE: Solid Diaphragms between Piles should be used where Ice or Drift may be serious.
The Distance from Crown of Roadway to Ground Surface shall not exceed 20 ft.
Piles shall have a Ground Penetration not less than half their Length, with a min. of 12 ft.
Each Pile Driven to sustain without Settlement The following Loads:-12'Span 15 tons, 14'Span 18 tons, 16'Span 22 tons, 18'Span 25 tons, 20'Span 28 tons.
Complete Permanent Records should be made of each Structure as Built, showing Pile Lengths, Penetrations, Pile Driving Data and all Modifications of this Design.
Side Elevation
Section X-X
Panel Length (L)
Rails may be Precast
Expansion Joints
Exp. Joint 3 Tarred Felt
Expansion Joint, Three Thicknesses of Tarred Paper or 1/4" Tarred Felt.
1 1/2" Bevel on all Exposed Edges of Caps and Posts.
Int. Caps, 6-3/4" Bars 18'8"
End Caps, 6-3/4" Bars 22'8"
Clear Span of Slab (S)
From Ctr. of Drain to Ctr. of Steel shall be a Min. of 2 3/4"
Slope 1 1/2:1
Grade Line
Riprap Slope when Indicated
Plan.
2" Drains with 1x6 Inlet
1 Extra Bar
1/2" Expansion Joint.
C.L. of Roadway and Bridge.
Main Reinforcement as per Table, Alternate Bars bent up.
1/2" Bars, 2' Cts. or Less
Concrete.
Rails of 1:3 mix. Max. Aggr. 1/4"
Piles, Caps, Slabs and Posts of 1:2:4 mix. Max. Aggr. 1"
Steel.
All Reinforcing Steel to be Deformed Bars.
(Sq. Twisted Bars not to be considered Deformed)
The Table is based on net Area of Bars as follows:-

Item	Panel Length	Clear Span	Min. Slab Thickness	Reinforcing Steel	Intermediate Panel		End Panel	
					Concrete	Steel	Concrete	Steel
	L	S	T	Main Reinforcement	Cubic Yards	Pounds	Cubic Yards	Pounds
Slabs and curbs...	14 Ft.	12 Ft.	$12\frac{1}{2}$ In.	$\frac{3}{4}''$ sq. $7''$ ctrs.	11.46	1070	12.29	1070
	16 Ft.	14 Ft.	14 In.	$\frac{3}{4}''$ sq. $6''$ ctrs.	14.48	1370	15.40	1370
	18 Ft.	16 Ft.	16 In.	$\frac{7}{8}''$ sq. $7\frac{1}{2}''$ ctrs.	18.38	1680	19.41	1680
	20 Ft.	18 Ft.	$17\frac{1}{2}$ In.	$\frac{7}{8}''$ sq. $6\frac{1}{2}''$ ctrs.	22.14	2130	23.26	2130
	22 Ft.	20 Ft.	$19\frac{1}{2}$ In.	$\frac{7}{8}''$ sq. $6''$ ctrs.	26.89	2460	28.13	2460
Railing..........	One rail post				0.0762 Cu. Yd. Concr.		14.45 Lb. Steel	
	One rail (section $3\frac{1}{2}'' \times 8''$) per lin. ft.				0.0072 Cu. Yd. Concr.		1.913 Lb. Steel	
Bents............	One pile 15 feet long				0.67 Cu. Yd. Concr.		174.0 Lb. Steel	
	One pile (section $1'-2'' \times 1'-2''$) per lin. ft.				0.0504 Cu. Yd. Concr.		11.6 Lb. Steel	
	One cap for intermediate bent				2.82 Cu. Yd. Concr.		238.0 Lb. Steel	
	One cap for end bent with walls				3.55 Cu. Yd. Concr.		283.0 Lb. Steel	

DESIGN DATA:
Steel in tension, 16,000 lb. per sq. in.
Concrete in compression 600 lb. per sq. in.
Concentrated load, one 15-ton typical truck.
Impact allowance, 30%.
Paving not to exceed 120 lb. per sq. ft.

FIG. 85.—(*Continued.*)

Quick-estimating Diagrams.—The following quick-estimating diagrams are convenient in determining economic type and rough appropriation estimates. The unit prices used are based on data in Chap. IX (p. 661). Weights of steel, if desired, can be obtained from Chap. IX (pp. 649 to 654).

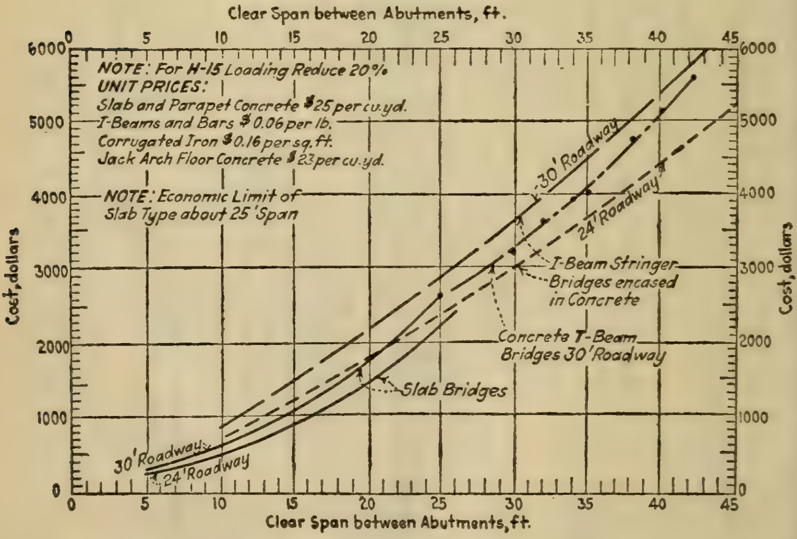


FIG. 86.—Typical cost curves. Small span bridge superstructures. H-20 loading. Based on standard bridges in the following illustrations. Slabs, Fig. 69, page 237. Steel I beam stringers, Fig. 76, page 275. Concrete T beam stringers, Fig. 73, page 252.

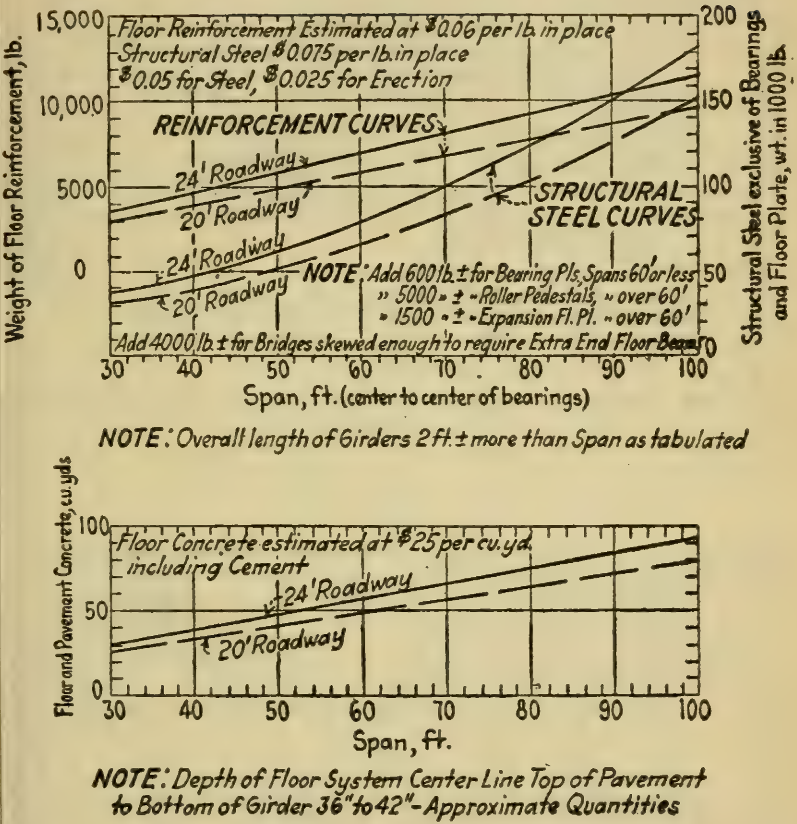


Fig. 87.—Approximate quantities typical plate girders. H-20 loading. Structural steel includes girders, floor beams and stringers.

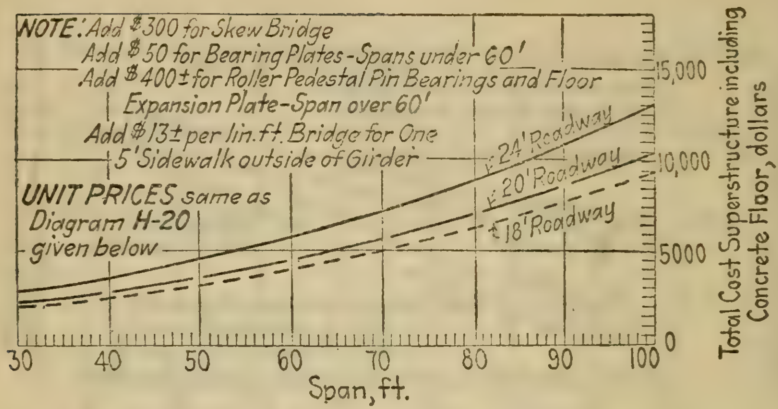


FIG. 88A.—Typical cost curves. Plate girder superstructures. H-15 loading.

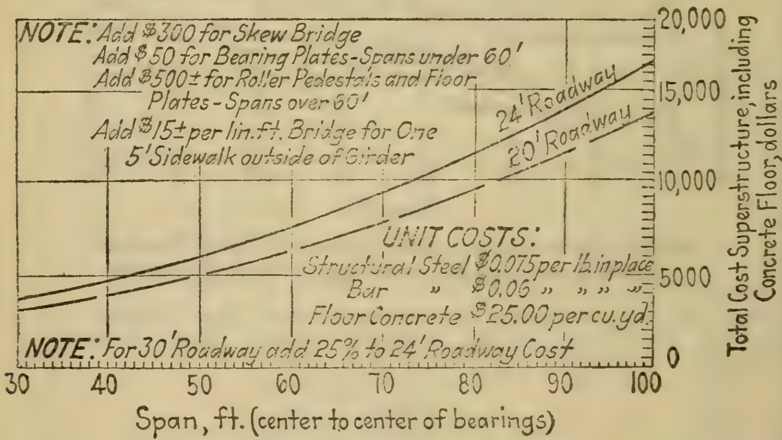


FIG. 88B.—Typical cost curves. Plate girder superstructures H-20 loading.

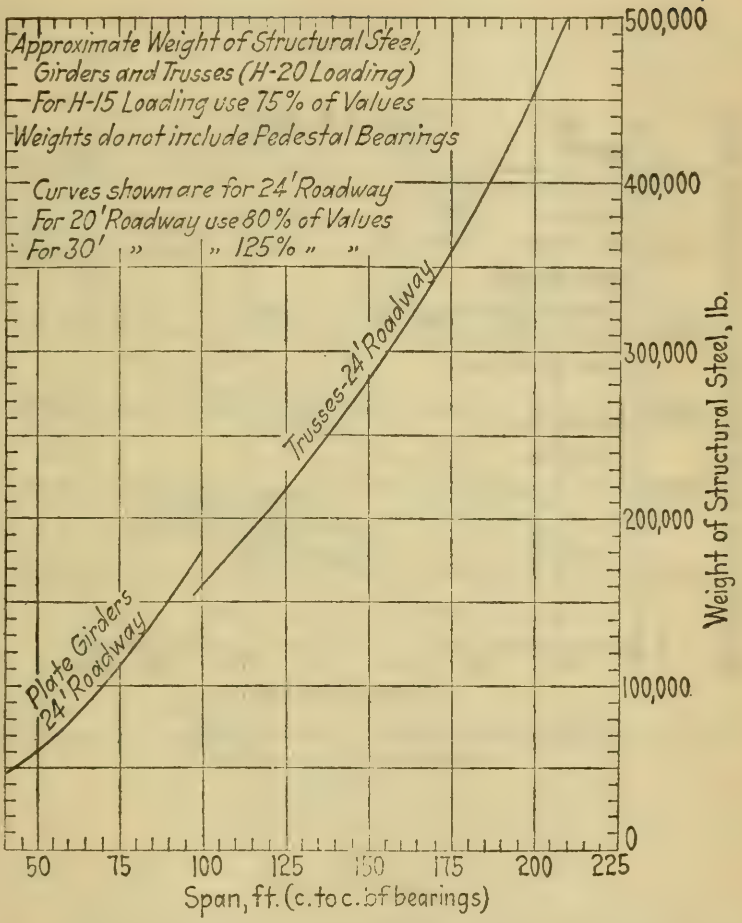


Fig. 89.—Approximate quantities structural steel plate girders and trusses. H-20 loading. These weights include girder or trusses, floor beams and stringers.

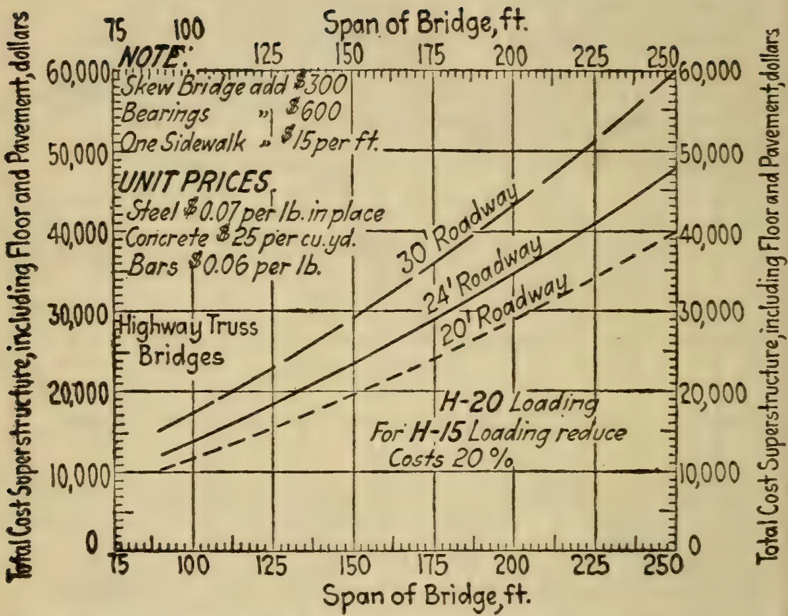


FIG. 90.—Typical cost curves. Truss bridge superstructures complete. H-20 loading.

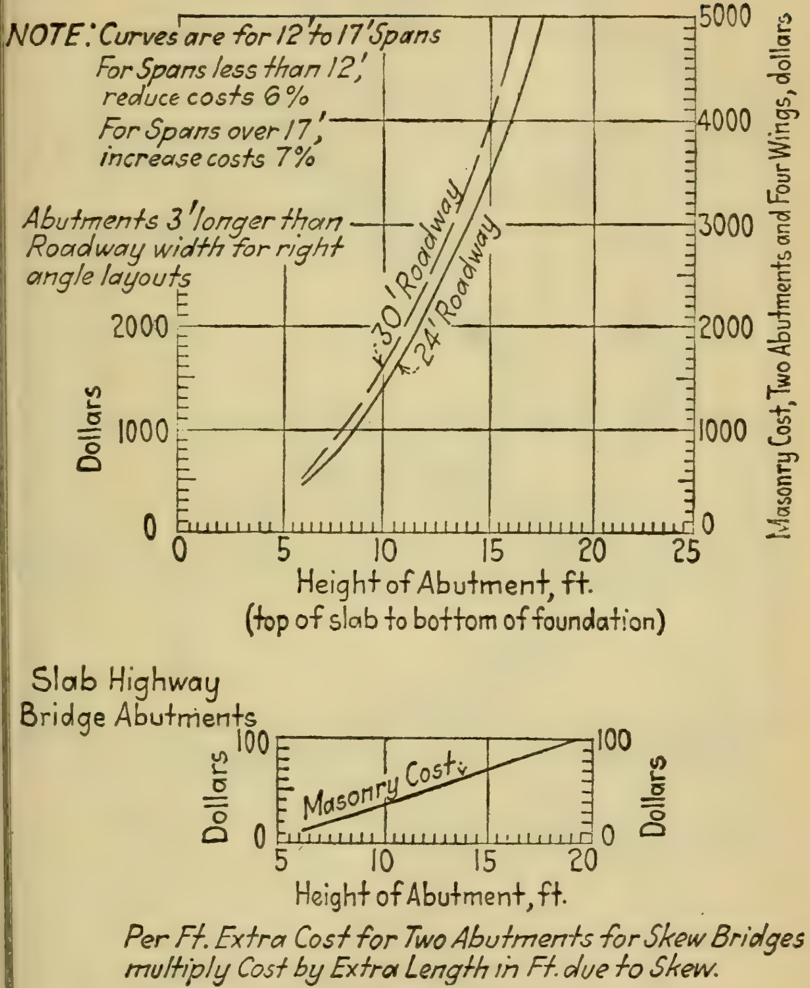


FIG. 91.—Approx. cost curves. Abutment masonry for slab type bridges. Spans 6′ to 25′ (unit price of concrete \$18 per c.y.).

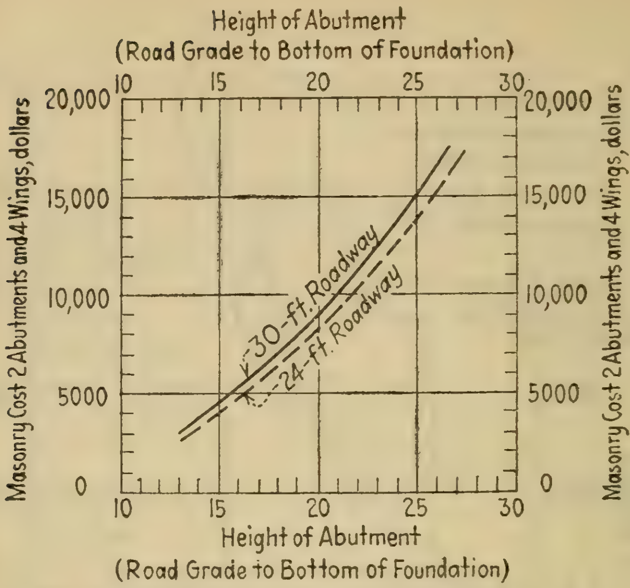


FIG. 91*A*.—Approximate cost abutment masonry. 2 abutments and 4 wings (rt. angle spans). I beam stringer bridges 25 to 45′ span (concrete $18 per c.y.).

APPROXIMATE COST OF MASONRY IN BRIDGE PIERS PER FT. LENGTH OF PIER SHORT SPAN BRIDGES (Concrete at $18 per c. y.)

Height of pier road grade to bottom of foundations in feet	Length of spans between piers			
	10′	20′	30′	40′
10	$ 8.50	$14.00	$18.00	$20.00
11	9.30	15.50	20.00	22.70
12	10.00	17.00	22.00	25.50
13	11.00	18.50	24.00	28.20
14		20.00	26.00	30.80
15		21.50	28.00	33.50
16			30.00	36.20
17			32.50	39.00
18			35.00	42.00
19				45.00
20				48.00

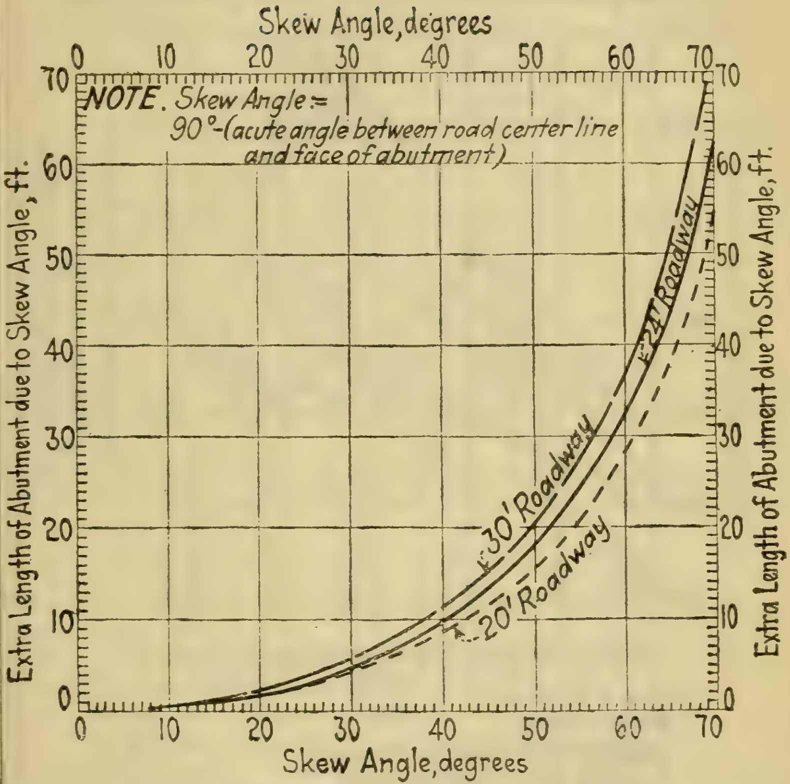


FIG. 92.—Extra length of abutment due to skew angle of bridge.

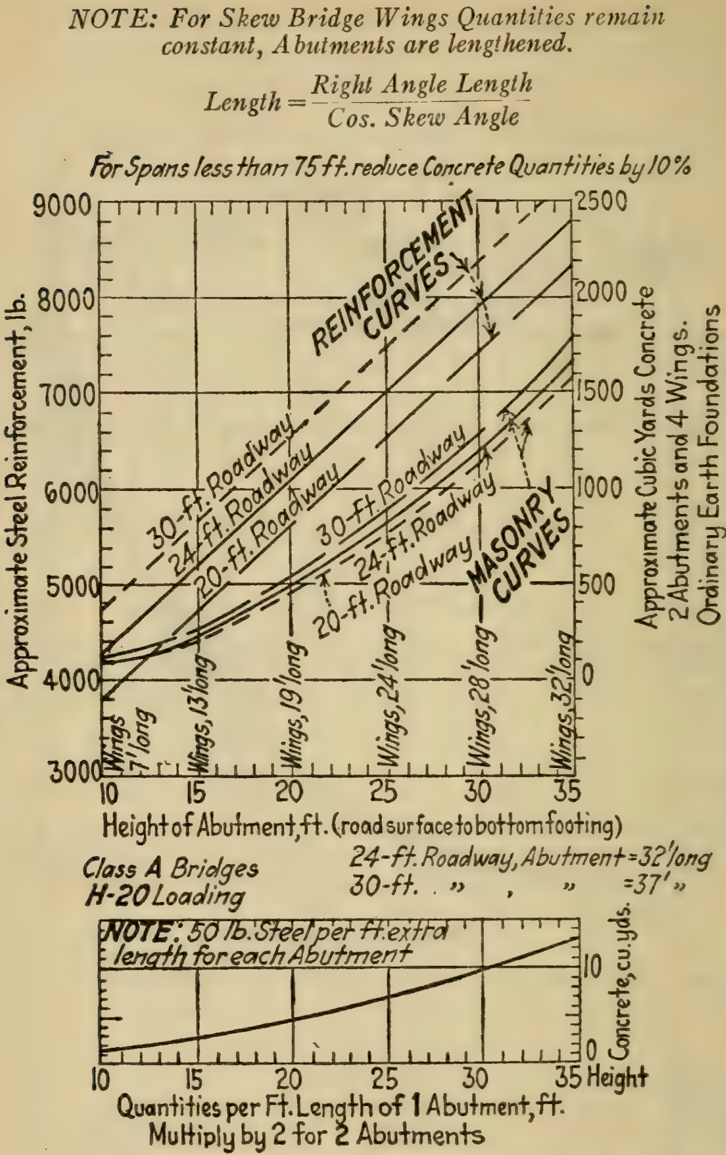


FIG. 93.—Approximate quantities of abutment masonry plate girder. Type of bridge. 40′ to 100′ spans.

GENERAL SPECIFICATIONS, PLATE GIRDER BRIDGE ABUTMENTS

24′ roadway girders 27 C. to C.
32′ length of abutment for rt.< layout.
Width bridge seat.

30 to 50′ spans	2.5 feet
50 to 100′ spans	3.0 feet

Back Walls. 18″ wide on top.
24″ wide at elev. bridge seat.
Spans 30 to 60 feet.
30″ wide at elev. of bridge seat.
Spans 60 to 100′ where roller bearings are used.

Top of backwall level with bottom of bridge floor at fixed end.
Top of backwall at expansion end level with top of floor and notched for floor plate and for approach pavement.
Back walls reinforced vertically and horizontally
Wings 24″ wide on top + 3″ for coping offset.
Bridge seat 18″ thick + 3″ coping offset.
Face batter 1″ to 2″ in 12″.
Footing course at least 4′ below stream bed.
Toe extension as needed. Normally 2 ft.
Width of abutment at top of footing course at least 0.4 h and preferably 0.45 h.
Width of abutment at bottom of footing course normally 0.5 h.
Rankine's earth pressure formula used in developing base pressure diagrams.

DIAGRAMS

Use equivalent live load surcharge of 1.5 feet. in computing foundation pressure.

MAXIMUM FOUNDATION PRESSURE

Pile loads	15 tons per pile
Soil loads per sq. ft.	
Silt	0.5 tons
Loam	1.0 tons
Stiff clay	3–4
Mixture clay and gravel	2
Firm gravel	4–5
Hardpan	6–7
Rock	8–20

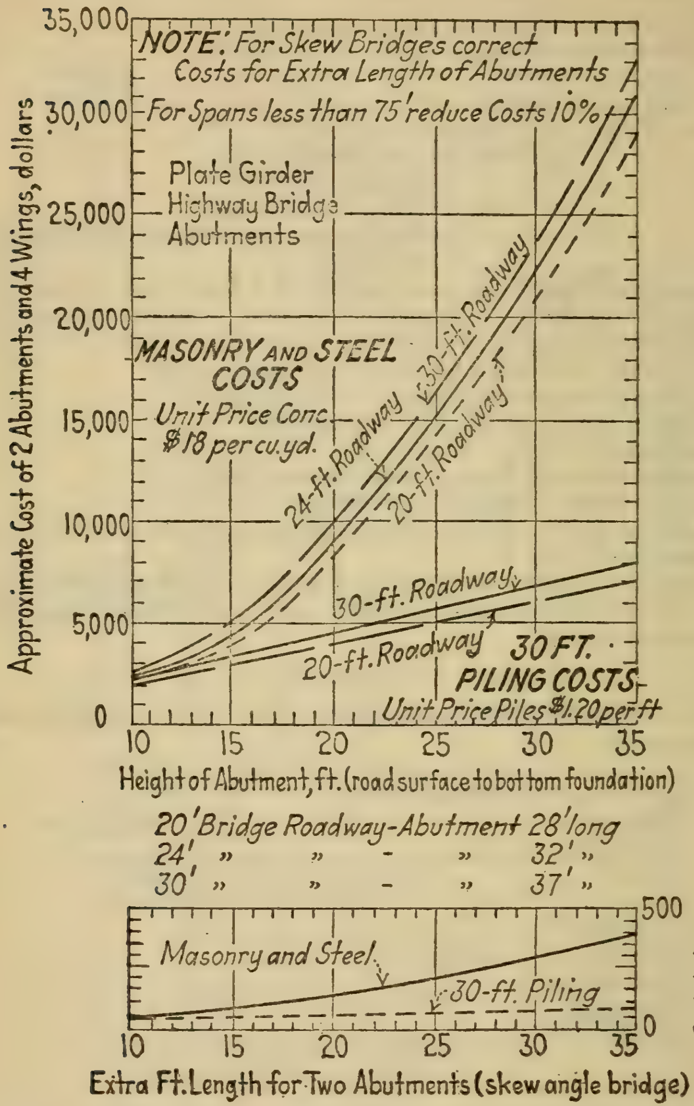


FIG. 94.—Typical cost curves abutment masonry. Plate girder bridges. 40′ to 100′ spans.

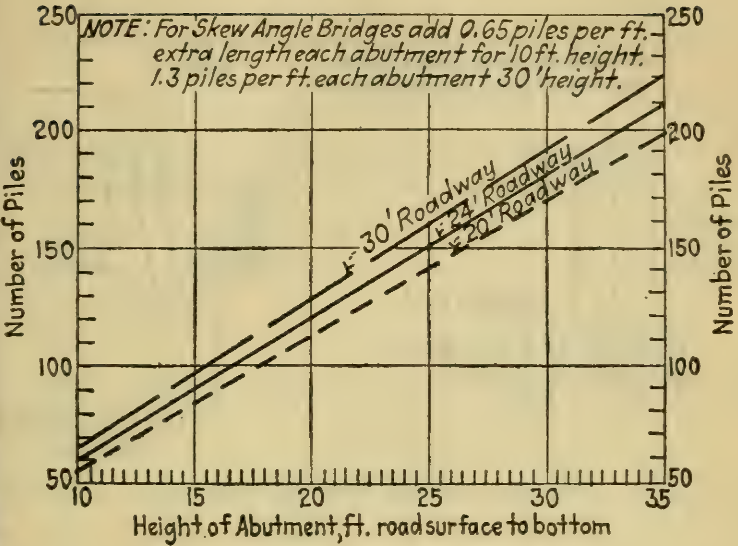


FIG. 95.—Approx. number of piles under girder abutments.

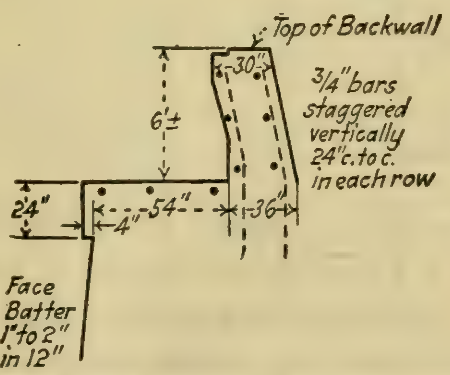


FIG. 96.—Typical seat and backwall long span truss bridge.

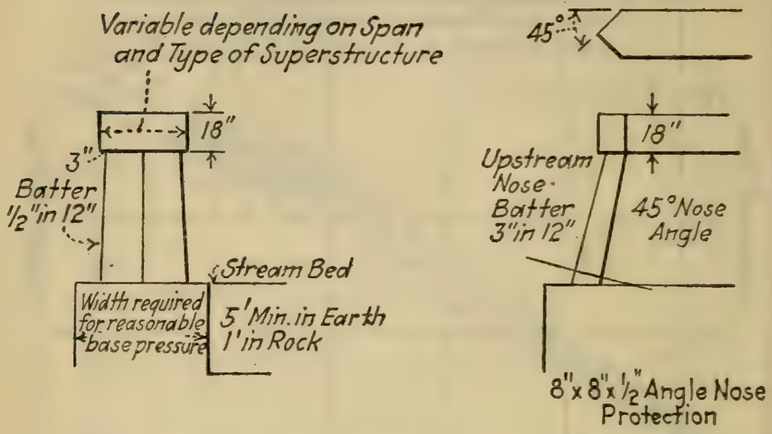


FIG. 97.—General dimensions of piers.

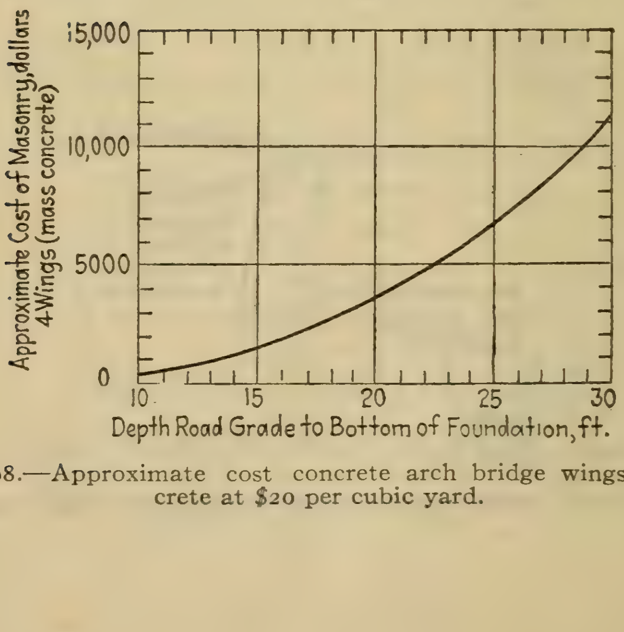


FIG. 98.—Approximate cost concrete arch bridge wings. Concrete at $20 per cubic yard.

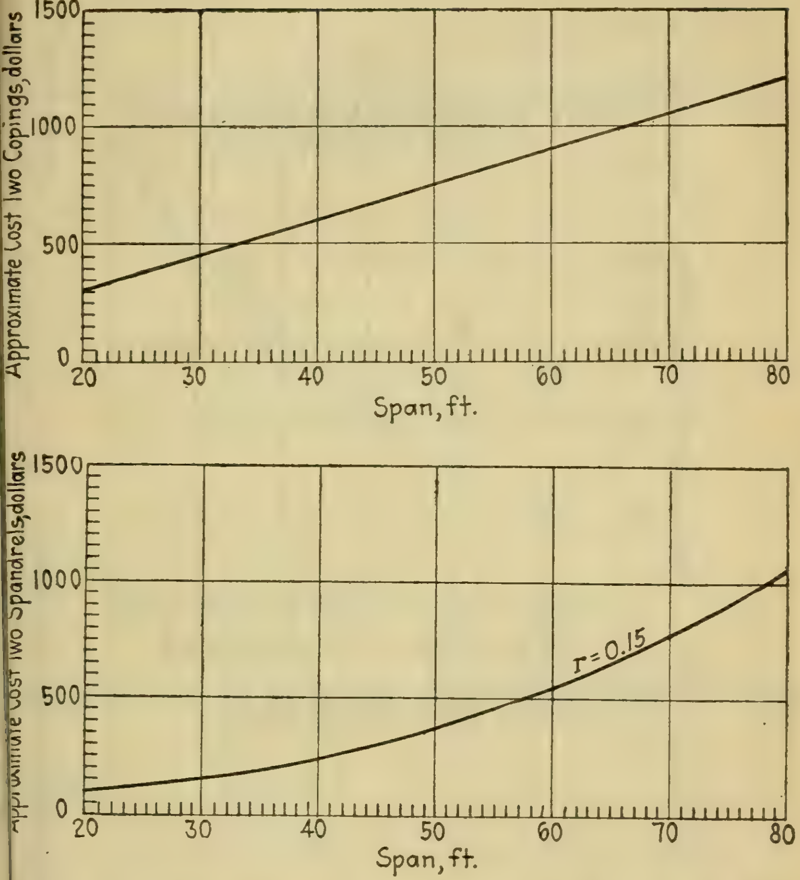


FIG. 99.—Approximate cost concrete arch bridge spandrels and copings. Rise ratio 0.15. (Concrete estimated $35 per c.y.)

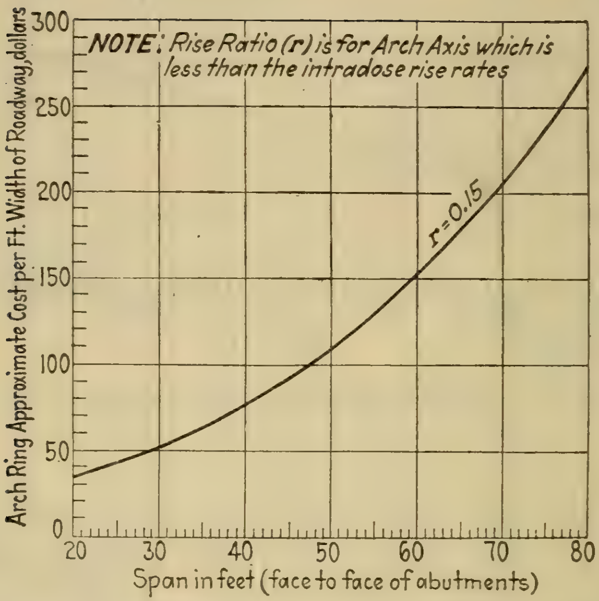
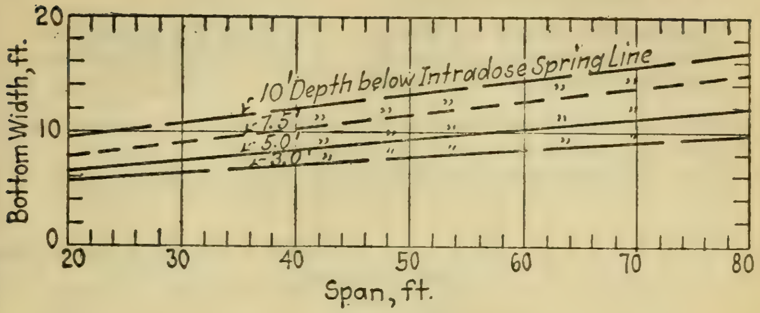


FIG. 100.—Approximate costs. Reinforced concrete arch rings. (Concrete $35 per c.y. incl. steel.)



Bottom Widths Abutments

NOTE: Curve marked 5' depth means bottom of foundation is 5' below intradose spring line

ABUTMENTS – Hard Pan or Rock Foundation

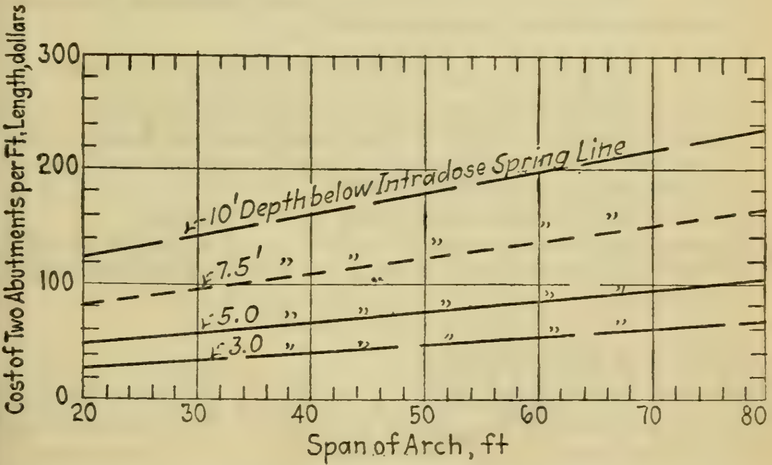


FIG. 101.—Approximate cost curves. Concrete arch. Bridge abutments. (Concrete at $20 per cubic yard.) Rise ratio of arch ring 0.15.

General Specifications, Reinforced-concrete Arches, Division 4

Rock or hardpan foundations:

Maximum pressure hardpan.....	6 tons per square foot.
Maximum pressure soft rock.....	8 tons per square foot.
Maximum pressure hard rock....	10–20 tons per square foot

Arches not recommended on pile foundations (12 tons maximum).
Arches not permitted on earth foundations
Arches not permitted with bottom ties (false arch) for spans over 10′.

Quantity and Cost Diagrams Based on Following Design Assumptions
(Trial Empirical)

Road grade 2.0′ above crown of arch, extrados crown thickness not less than one-sixtieth of span and varied to agree approximately with Schwada's formulas for highway arches (Ketchum, p. 417).

Spring thickness of arch ring:
3.0 × crown thickness for rise ratio of 0.125.
2.8 × crown thickness for rise ratio of 0.15.
2.5 × crown thickness for rise ratio of 0.20.
2.0 × crown thickness minimum for any condition.

Curve of trial arch axis based approximately on Cochrane's formulas for filled spandrel arches:

$$Y = \frac{4rL}{1 + 3r}(C^2 + 24\,C^5 r) \text{ (Hool and Johnston, p. 670).}$$

Minimum longitudinal arch reinforcement 1% at crown.
Transverse reinforcement to take full thrust of earth against spandrels and never less than 0.3% of section area at crown.
Arch reinforcement symmetrical.
Spandrel walls cantilever design up to 5 ft. height.
Gravity Spandrels or cross tie walls above 5 ft. height of fill.
Stirrups ¼″ circular spaced twice the depth of the arch ring at crown.

Unit Prices

Excavation as given on page 661.

Foundation and wing concrete..............	$20 per cubic yard.
Arch ring and spandrels......................	$35 per cubic yard.
Bar reinforcement..........................	6 cts. per pound.

Estimate graphs prepared for following parts of structure:
1. Arch ring 30 to 100′ spans, 0.10 to 0.25 rise ratio.
2. Wings.
3. Spandrels.
4. Foundations and abutments.
5. Piers.
6. Vertical-axis ordinates for Cochrane-formula-filled spandrels, different rise ratios (see p. 1086).
7. Table of arch axis angle with horizontal at spring line for different rise ratios (see p. 1086).

OUTLINE OF TYPICAL BRIDGE PRELIMINARY DESIGN REPORT

1. *Condensed recommendations:*
    - Location and skew angle of new bridge
    - Required waterway area
    - Channel improvements
    - Foundations, abutments, and piers
    - Superstructure:
        - Type
        - Span
        - Skew angle
        - Roadway
        - Sidewalks
        - Provisions for pipe lines or cables
        - Live load
        - Elevation of new structure
        - Camber
    - Temporary bridge for maintaining traffic
    - Incidental items
    - Estimated cost
2. *Detailed data and discussion.*
    - *a.* Location and skew angle of existing and proposed bridge
    - *b.* Waterway area of bridge:
        - Watershed
        - Probable, maximum run-off
        - Normal flood flow velocity
        - Ice and débris in stream
        - High- and low-water elevations
        - Waterway area of adjacent bridges on the same stream
    - *c.* Channel conditions and required improvements
    - *d.* Foundation conditions
    - *e.* Condition of existing bridge and other bridges on same stream (type and suitability)
    - *f.* Abutments, piers, and superstructure:
        - Type considering economic and esthetic requirements
        - Span (single or multiple)
        - Roadway width considering future traffic volume.
        - Sidewalks for pedestrians
        - Provision for pipe lines or cables
    - *g.* Temporary bridge for maintaining traffic
    - *h.* Incidental items:
        - Rip-rap
        - Approaches
    - *i.* Estimate of cost:
        - Source of materials
        - Alternate estimates different types, widths, and loads

FIELD INSPECTION AND PRELIMINARY DESIGN REPORT

Bridge 29, Livingston County
Bridge 5, Road 1247
Sta. 374 + 50*A* ±

Field Inspection: by W. G. Harger and R. W. Anderson
Preliminary Survey: by R. W. Anderson
Condensed Recommendation:
- New road approach relocation (see general layout, Fig. 48, p. 184)
- Right-angle structure recommended
- Required waterway below elevation 564.0 and above 538.0 = 5200 sq. ft. minimum.
- River channel to be improved
- Pile foundations
- Mass concrete abutments (see detail report)
- Superstructure:
    - Type—pin connected through steel truss
    - Clear span between abutments, 200′ minimum, 245′ maximum (see detail report)

Skew angle—no skew (right-angle structure)
Roadway—departmental minimum Class II road
Sidewalks—not required
Pipe line and conduits—none
Live load—H-15 or H-20 suitable
Elevation bottom of floor or truss steel 568.0 plus,
Elevation roadway surface
573.0 minus.
Camber—standard (approximate 12″)
No temporary bridge
Abandon small bridges 4 and 6
Design of new approaches (see detail report)
Use concrete shoulders and rip-rap on slopes
Estimated Cost (rough preliminary; see detail report)

Road approaches (215′ span bridge C to C bearings	$ 24,000
(255′ span bridge C to C bearings	23,000
River channel improvement 215′ span bridge	10,500
River channel improvement 255′ span bridge	11,000
Bridge proper (see detail report):	
22′ roadway (one high and one low abutment 255′ span H-15)	72,000
22′ roadway (two high abutments 215′ span H-15)	80,000
30′ roadway (two high abutments 215′ span H-20)	105,000
30′ roadway (one high and one low abutment 255′ span H-20)	102,000
Total minimum cost (H-15-22′ roadway 250′ span)	105,000
Total maximum cost (H-20-30′ roadway 215′ span)	140,000

Detail Data and Discussion

Location and Skew Angle of Bridge.—The location of the existing bridge is poor both on account of sharp-approach road curves and poor flow conditions for the river, which retard the natural flow and cause ice jams and scour.

The attached general layout shows the proposed new location, which gives easy road alignment and a smooth flow for the Genesee River (see Fig. 48, p. 184). The new location also permits the use of a right-angle structure, which is desirable.

Required Waterway Area.—The Genesee River is subject to quick, severe floods with a large and rapid change in depth. It annually overflows its banks from Mt. Morris to Rochester and floods the entire valley for widths of from ¼ to 1½ miles. Road 1247 is often covered with water from 1.0 to 2.5′ deep between Stas. 300 to 390, but these conditions rarely last over from 3 to 7 days and usually occur only once a year.

It has been customary to design all bridges over this part of the river to span the natural channel with the steel high enough to be above ice jams or floating débris (large trees), making no serious effort to raise the approaches above high water and to force all water under the main channel bridge.

Proposed water power storage dams, however, at Mt. Morris and Portageville, which may be constructed within 10 to 15 years, will tend to reduce the peak of the floods and it may easily become desirable to raise road No. 1247 above high water across the river flats to give uninterrupted year-around service to traffic.

It seems desirable to provide for both present and possible future conditions. Present conditions require a clear span of approximate 200 to 205′ to span the normal channel at the crossing and an elevation of bottom of floor steel not lower than 568.0 to clear ice jams and floating trees.

Possible future flow conditions may be summarized as follows:

The Jones Bridge gaging station of the Rochester Gas and Electric Corporation located about 1½ miles upstream records normal floods for the last 16 years at 24,000 sec.-ft. approximately. In 1916 an extreme flood ran 46,000 sec.-ft. for 1 day and 55,000 sec.-ft. for a short period in that day. The effect of the proposed storage dams is, of course, problematical, but they will certainly reduce peak flows. According to the engineers of the Gas and Electric Corporation, a future peak flow of 30,000 to 35,000 sec.-ft. after completion of the Mt. Morris dam would probably be a very safe maximum

flow allowance. It is recommended that future maximum flow under the bridge be based on 35,000 sec. at 7′ per second requiring a minimum flood-flow area of approximate 5000 sq. ft. This flood-flow area lies between Elevation 538.0 low water and 564.0 present high water, which it would be undesirable to raise due to damage claims and would require a clear span of approximately 200′. The previous discussion of present condition requirements indicated that a span of 200 to 205′ was required with a flood-flow area of 5300 sq. ft. between Elevations 538 and 564, which shows that any bridge satisfactory for present conditions should serve possible future conditions.

The present bridge on Road 1247 (No. 5) has a flow area of 5300 sq. ft., but 500 sq. ft. ± is scour area below Elevation 538.0, making the net effective flood-flow area 4800 sq. ft. The most recently constructed bridge over the Genesee River at Geneseo, where the watershed area is only slightly greater than at Road 1247, used a span of 222′ with a flood-flow waterway area of 5000 sq. ft. ±.

Spans of Genesee River bridges are as follows:

Bridge	Clear span, feet	Food-flow area under bridge, square feet
Bridge 29 (present)	180 + 130 = 310	5300
Bridge 29 (proposed)	200 to 205 minimum	5300
Jones bridge 1½ miles upstream	174 + 40 = 214	5000
Genesee, Road 718	222	
Avon, Road 5273	150	
Industry, Road 1393	235	
Ballantyne	215	
Browns Bridge, Road 1499	204	

A minimum clear span of 200 or 205′ and a minimum waterway area of 5200 sq. ft. between Elevations 538 and 564 should serve satisfactorily.

It will be well worth while to consider a maximum clear span of 240 to 245′ with the west abutment on top of the river bank. This will undoubtedly cheapen the bridge, as shown in the comparative estimates attached, and will probably serve satisfactorily for present conditions, as there is not much scour on the west side of the channel. Considering the future possibility, however, of forcing all the water under the bridge at a higher velocity, it is possibly safer to use two high abutments and the shorter spans, although I personally favor the cheapest first cost, as I do not consider there is much probability of scour and if it occurs it can be stopped at a small cost.

Channel Conditions.—Present channel conditions poor (see general layout and photos). Current velocity is needlessly checked; ice jams form easily and bad scour occurs on east bank. The material in the banks is river silt underlaid with clay. It scours easily.

The solution shown on the general layout seems obvious and not susceptible to much variation. Straighten channel, rip-rap east bank upstream heavily for at least 150′ above the bridge and for short distance below the bridge. Rip-rap new bank on west side for at least 80′ north and south of bridge. Use channel excavation for approach road fills. As a matter of fact, the channel excavation adds nothing to the total cost of this project, as borrow for the road approaches would have to be made in any case.

Foundation Conditions.—Soil river silt and clay; piles required. The only doubtful point is length of piles. It is better to pay the contractor for five or six test piles to determine this item than to waste money at this time with a well-drilling outfit to test for possible underlying hardpan, as it is known from scour channel of river that no hard strata are high enough to be used directly as foundation for masonry. For piles under abutment on top of bank above low-water elevation use concrete or creosoted piles.

Condition of Existing Structure.—Poor. Built in 1866. Safe load, 3 tons minus. Roadway 15.0′. Spans 180 + 130 = 310′ total. Abutments and piers excellent masonry. Reuse as plums in abutment concrete or as rip-rap.

Types of Bridges over Genesee River.—All bridges from Mt. Morris to Rochester are steel-truss bridges and only two of these bridges have piers;

these piers are not central piers and act in conjunction with short-approach spans. Central piers are not considered desirable on this river.

Abutments, Piers and Superstructure.—Piers not suitable or economical.

East abutment should be a high abutment with pile foundations and face sheeting to prevent undercut scour. Mass concrete with 20% plums utilizing old masonry is advised, as this abutment will have to take considerable punishment from ice, etc. Elevation bottom concrete 535.0 minus, which is 4′ below surface of low water.

West abutment can be either high abutment at bottom of bank or low abutment on top of bank. Piles will be required for either location.

Best type of superstructure probably steel through truss parabolic upper chord pin connected solid floor similar to recently constructed bridges at Industry, Ballantyne, and Geneseo.

Design loading and roadway width should be carefully considered, as they result in considerable difference in cost for this structure.

This road carried 668 vehicles 1925 traffic census. Character of traffic largely pleasure vehicles (light motors). This is a secondary route and there is no possibility of it ever exceeding 3000 vehicles daily which can be served by a two-lane bridge. No provision for pedestrian traffic is necessary.

The A.S.C.E. recommend H-15 loading for these conditions and a minimum 20′ roadway. The Hoover Committee on Highway Safety recommends a minimum roadway of 22′ on account of busses for these conditions. The departmental standards use H-20 and 30′ minimum roadway which, while they are desirable on really heavy-traffic roads, cannot be considered as necessary for this particular case.

Temporary Bridge.—Not feasible.

Road Approaches.—Concrete pavement with concrete and rip-rapped shoulders similar to Road 1393, 4.2% maximum grade. Elevation of grade across flat 562.5, which is the same as present approaches and will not increase ponding on upstream side of road with consequent claims.

Abandon small bridges 4 and 6.

ROUGH COMPARATIVE COST ESTIMATES BRIDGE 29, LIVINGSTON COUNTY; BRIDGE 5, ROAD 1247

Suprestructure:

215′ span C to C of bearings H-20-22′ roadway	$35,000
215′ span C to C of bearings H-20-30′ roadway	48,000
215′ span C to C of bearings H-15-22′ roadway	28,000
215′ span C to C of bearings H-15-30′ roadway	39,000
255′ span C to C of bearings H-20-22′ roadway	45,000
255′ span C to C of bearings H-20-30′ roadway	62,000
255′ span C to C of bearings H-15-22′ roadway	36,000
255′ span C to C of bearings H-15-30′ roadway	50,000

ABUTMENTS (STEEL AND MASONRY ONLY)

($14 per cubic yard and $0.06 per lb. 20% plums old masonry)

Two high abutments (22′ roadway)	$35,000
Two high abutments (30′ roadway)	39,000
One high and 1 low (22′ roadway)	21,000
One high and 1 low (30′ roadway)	24,000

ABUTMENT PILES AND SHEETING IN PLACE

($1 per foot, $80 per M ft B.M.)

30′ roadway

Two high abutments	$10,000 + 1,000 = $11,000
One high and one low	7,000 + 1,000 = 8,000

ABUTMENT EXCAVATION AND BACKFILL

(Below Elevation 540 and back of face of abutments)

Two high abutments	$8,000
One high and one low	6,000

ROUGH ESTIMATE ROAD APPROACHES

(Same general design as Industry River Flat Road 1393 concrete shoulders, down to natural surface of ground on light fills and rip-rap on higher fills. Borrow fill to be obtained from river channel widening.)

	215′ span	255′ span
Pavement (concrete 18′ wide) at $3.20 per sq. yd.	$10,300	$10,000
9″ concrete shoulders (reinforced) at $3.00. per sq. yd.	5,400	5,400
400 cu. yd. ± rip-rap at $4 cu. yd.?[a]	1,600	1,400
Guard rail at $1.50 per lin. ft.	1,800	1,700
Excavation 500 at $1	500	500
10,000 cu. yd. ± borrow fill (extra cost for placing channel excavation at 40 cts.)	4,000	3,500
Clearing and grubbing L. S.	500	500
Total	$24,100	$23,000

[a] Price of rip-rap not figured closely.

Rough Estimate Channel Improvement

	215′ span	255′ span
600 cu yd. ± excavating old masonry at $4 [b]	$ 2,400	$ 2,400
500 cu. yd. ± rip-rap 500 / 700 } at $4?[b]	2,000	2,500
10,000 cu. yd. ± earth excavation at 60 cts.	6,000	6,000
Clearing and grubbing, L. S.	300	300
Total	$10,700	$11,200

[b] Old masonry used for rip-rap or for plums in abutment concrete.

Note.—Channel excavation to be used in road approach fills or, if wasted, contractor to furnish other borrow at his own expense.

Photographs and detail study profiles and general layout attached.

Signed
W. G. Harger,
Bridge Eng. Div. No. 4
Oct. 31, 1925

FIELD INSPECTION AND DESIGN REPORT BRIDGE 25, LIVINGSTON COUNTY BRIDGE 1, ROAD 1247 STA. 248, BEARDS CREEK

Field Inspection: by W. G. Harger and R. W. Anderson, Oct. 20, and 21, 1925.

Condensed Recommendations:

Location and skew angle (see general layout):
- New road approach center line.
- Intersection center lines bridge and New Creek Channel Sta. 247 + 62±.
- Skew angle 48°.

Required waterway area: 500 sq. ft. minimum.
540 sq. ft. recommended.
- Measured at right angles to stream flow and between Elevations 576.0 and 585.0.

Channel improvements (see general layout):
- New outlet channel 200′ long.
- Cut off small bend in east bank of inlet channel—250′ above bridge to straighten channel.

Foundations abutments and piers:
- Short piles down to hardpan (piles 15′ long ±).
- Standard concrete abutments.
- Piers are unsuitable for this bridge.
- Elevation of bottom of foundation concrete 571.5.
- Foundation excavation will have to be sheeted and pumped.

Superstructure:
Type steel-plate girder (concrete floor).
Span 85′ clear between faces of abutments 90′ ± C. to C. of bearings.
Skew angle 48°.
Roadway departmental minimum for Class II road.
Sidewalks—none required.
Pipe lines or conduits—none.
Live load—H 15 or H 20 suitable.
Elevation bottom of steel 586.5+.
Elevation of roadway surface 590.5−.
Camber—standard camber.

Temporary bridge:
Should be provided if this bridge is let by a separate contract. If let as part of road reconstruction no temporary bridge needed.
Good detour 1 mile extra distance.

Incidental items:
Rip-rap approach fills 100′ each side of bridge on north side of road and 60′ each side of south side of road.
Future road approach grade across valley 587.0.

Estimated Cost:
Estimated cost of new bridge and channel work exclusive of new approaches as follows:
22′ roadway (minimum.......................... $31,000
30′ roadway (maximum)......................... 38,000

Detail Data and Discussion

a. **Location and Skew Angle of Existing and Proposed Bridge.**—The accompanying general layout and the testimony of field indications and local residents show that the existing bridge is poorly located and causes scour and needless checking of flow and ice jams. The new bridge should be moved west about 30 to 35′ and should be constructed on a skew angle of approximately 48°.

b. **Waterway Area Required under Bridge.**—Watershed 30 sq. miles classed as midway between rolling and hilly country.

Probable maximum flood 3500 sec.-ft.

Probable flood velocity of flow, using actual stream channel cross-section and slope of stream 6 to 8′ per second based on Church's diagrams, Kutter's formula.

Flow area under bridge based on 3500 sec.-ft. at 7′ per second should be safe—500 sq. ft. minimum.

Waterway area of other bridges on stream are not of much value, as conditions of flow are entirely different. They are tabulated as follows and indicate in a general way that it is desirable to use about 540 sq. ft. under this bridge.

Waterway Area of Adjacent Bridges over Beards Creek

Location	Span		Waterway area, effective at right angles to stream flow, square feet	Road approaches, overflow area, square feet	Total area, square feet
	Skew feet	Effective right angle feet			
Bridge number 25...	86′	55±	460±	Indefinite	Indefinite
Combined four bridges of Beards Creek branches upstream...........	..	84	470	....	480
First bridge downstream[a]..........	..	41	300	....	300
Second bridge downstream Pennsylvania Ry.[a].........	..	50	350	Indefinite	Indefinite
Third bridge downstream, road 1247[b].	..	40	540′	Indefinite	Indefinite

[a] These bridges are admittedly too small.
[b] Back water from river reduces value of these data.

c. **Channel Conditions.**—Slope of stream, 0.25%. Present channel very crooked at bridge site and needs straightening (see general layout). Large amount of ice which jams due to crooked channel. Proposed channel straightening shown on general layout approximate 900 cu. yd. excavation. It is impracticable to lower channel under bridge below elevation 576.0.

d. **Foundation Conditions.**—Light soil underlaid with hardpan or shale at elevation 562 ±. Present abutments on short piles down to hardpan. Short blunt end piles down to hard pan recommended figured for 15 tons per pile.

e. **Condition of Existing Bridge 25 and Other Adjacent Bridges over Beards Creek.** *Bridge* 25.—Concrete abutments in fair condition, 86′ clear span, steel pony truss plank floor. 15′ roadway. Steel in poor condition. Safe load 4 tons figured by W. G. Harger.

Bridge 25 should be condemned as soon as funds become available for rebuilding.

Six bridges over this creek are concrete-slab structures and two are single-span steel trusses or girders. One bridge has a central pier and has not been satisfactory due to scour and ice jams. Central piers are apparently not desirable on this stream.

f. **Abutments, Piers, and Superstructure.**—Piers are undesirable on this stream.

For a single-span bridge on pile foundations, the plate girder type is economical, and for this location appearance has no weight in the decision. A plate girder with solid floor is recommended.

Considering the facts that it is impracticable to lower the stream bed and undesirable to raise high-water elevation on account of flooding road across flat, a span of 57′ at right angles to stream flow is recommended, which requires 85.0′ clear span between faces of abutments measured parallel with proposed new road center line. This will give a waterway area of 513 sq. ft. measured at right angles to stream flow below Elevation 585.0, which is present high water.

Road 1247 is a Class II highway which carried 668 vehicles according to traffic census of 1925. Making ample allowance for future growth, this road will be amply served with a two-lane bridge requiring a minimum roadway of 22′.

Sidewalks are not required nor is any provision necessary for pipe lines, conduits, or electric trolley tracks.

Considerable heavy-unit trucks use this road, which warrants an H–20 loading, although H-15 would probably serve satisfactorily.

Bottom of steel girders or floor of superstructure should be at Elevation 586.5 or higher.

Road grade 590.5 or as much lower as possible so long as the bottom of steel is not less than 586.5.

g. **Temporary Bridge.**—Good detour 1 mile extra distance.

Temporary bridge recommended in case this bridge is let as a separate contract. No necessity in case it is included in a reconstruction road contract.

h. **Incidental Items.**—Approach fills to be rip-rapped. Approach alignment changed to eliminate reverse curve east of bridge and to ease up west approach. New tangent advised from Sta. 244 of present road to 253 + 50 ± with easy curves at 244 and 253.

i. **Estimate of Cost.**—Rough appropriation estimates of cost are as follows, using H-20 loading:

	Minimum, 22′ roadway	Maximum, 30′ roadway
Superstructure	$13,500	$18,300
Abutments and piles	13,300	15,000
Excavation	2,500	3,000
Channel cleaning	700	700
Temporary bridge	1,500	1,500
Right of way	500	500
Totals	$32,000	$39,000

Signed
Bridge Engr.
Div. No. 4

LONGITUDINAL DRAINAGE

Longitudinal drainage covers the normal road-section ditch, special creek channels, the protection of ditches from scour on steep grades, the use of storm water sewers on long grades where it is not possible to get rid of the surface water by diversion from the road, and driveway culverts.

Carrying Capacity of Ditches.—It is desirable to use as shallow and small a road ditch as possible on the score of both safety and economy of grading (see sections p. 143). All ditches will clog more or less in the winter with snow and ice, so that the size of the ordinary road ditch is more a matter of judgment based on experience than it is of figures. Intercepting ditches carrying the run-off from considerable areas should be figured, using run-offs similar to culvert design methods.

Creek channels and intercepting ditch capacities can be figured. Church's diagrams of Kutter's formulas using a value of $N = 0.035$ furnish a quick, easy method of approximately the required size (see Table 52, p. 195).

In order to give a fairly definite idea of the limitations of the use of the shallow and medium road ditches shown in Fig. 102, the following conditions are outlined. As a rule, the capacity of the roadway ditch is taxed by short, sharp summer showers. As

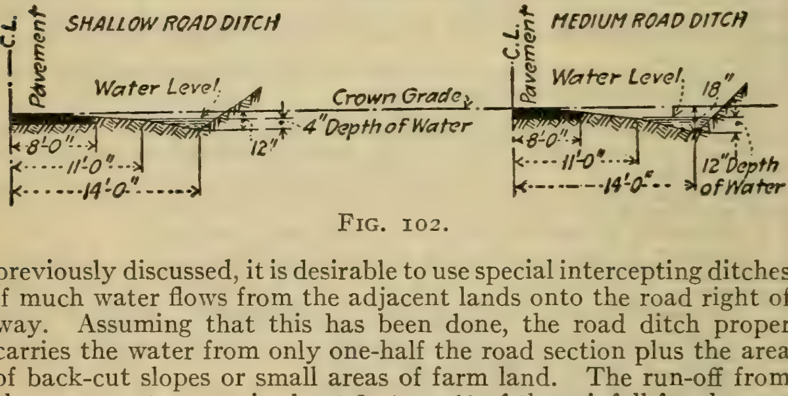


FIG. 102.

previously discussed, it is desirable to use special intercepting ditches if much water flows from the adjacent lands onto the road right of way. Assuming that this has been done, the road ditch proper carries the water from only one-half the road section plus the area of back-cut slopes or small areas of farm land. The run-off from the pavement proper is about 80 to 90% of the rainfall for showers of, say 10-min. duration. The run-off from the shoulders and backslopes is perhaps 60% under favorable conditions. An average run-off of about 75 to 80% of the rainfall for the area of one-half the total right-of-way width can be assumed. This means, as a rule, that the shallow ditch should not be used for more than 400′ from a summit or below a ditch relief culvert on flat grades nor more than 800′ on moderate grades. Current practice recognizes this general principle by the use of deeper and larger ditches in flat country than in rolling country. The medium ditch will serve satisfactorily for at least 2000′ from summits, provided it does not carry side land run-off.

To give a rough idea of the carrying capacity of the ditches condensed Table 59 is given for a few ordinary cases.

TABLE 59.—APPROXIMATE CARRYING CAPACITIES AND VELOCITIES OF FLOW, ORDINARY ROAD DITCHES GRASSED OVER

Grade of road ditch, per cent	Shallow ditch (Fig. 102)		Medium ditch (Fig. 102)			
			Depth water, 12″		Depth water, 6″	
	Velocity, feet	Capacity second-feet	Velocity, feet	Capacity second-feet	Velocity, feet	Capacity second-feet
1.0	0.7	0.4	2.0	4.0	1.1	0.5
2.0	1.1	0.7	3.0	6.0	1.7	0.8
3.0	1.3	0.8	3.6	7.2	2.0	1.0
4.0	1.5	0.9	4.2	8.4	2.3	1.2
5.0	1.7	1.0	4.8	9.6	2.6	1.3
6.0	1.8	1.1	5.3	10.6	2.8	1.4
7.0	2.0	1.2	5.6	11.2	3.1	1.5
8.0	2.2	1.3	6.0	12.0	3.4	1.7
9.0	2.3	1.4	6.5	13.0	3.6	1.8
10.0	2.5	1.5	7.0	14.0	3.8	1.9

Protection of Ditches from Scour.—The rate of grade at which ditch protection from scour is advisable depends on the soil and velocity of flow; the velocity of flow depends on the shape of ditch and volume of water.

Soils scour at approximately the following velocities:

Sand.................................. 2–3 ′ per second
Loam.................................. 2–3½′ per second
Firm gravel............................ 5–6 ′ per second

Table 59 is inserted to show in a general way the effect of shape of ditch and depth of flow on velocity and indicates that ditch protection must be provided at lower rates of grade for a large than for a small flow. This agrees with current practice, which favors the use of cobble or cement gutter at approximately the following rates of grade.

Current Practice in Ditch Protection.—Where the volume of flow is less than 1.0 sec.-ft., ditch protection is not needed on hills less

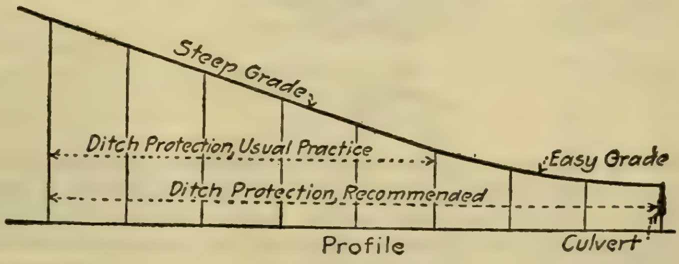


FIG. 103.

than 7% grades. Where the volume of flow exceeds this amount, ditch protection is advisable on sandy or loam soils on grades steeper than 3% and in firm gravel on grades of 5% or greater.

This means that, as a rule, on steep grades some kind of gutter is desirable for ditches more than 200 to 300′ from a summit or below a ditch relief culvert. It is practically impossible to carry a large volume of water down a steep grade, so that every effort should be made to divert the flow above the grade or remove it from the surface by ditch relief culverts or storm sewers.

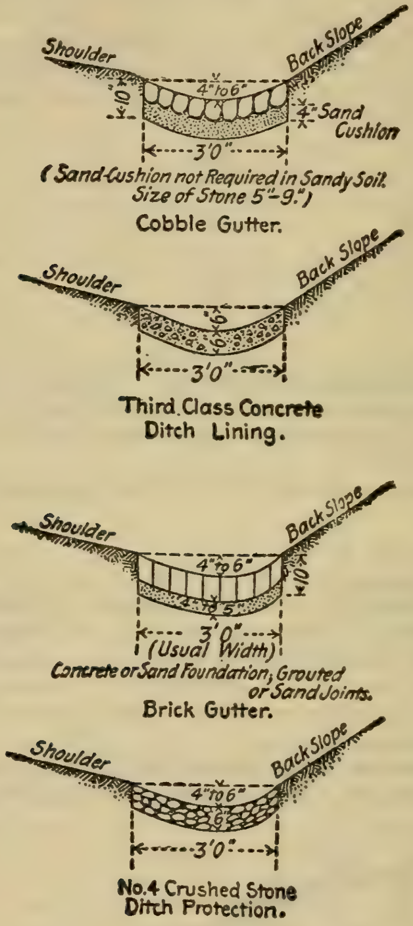


FIG. 104.

Where ditch protection is used it is good practice to carry it for at least 200′ along the road after the foot of the steep grade is reached, and preferably to the first culvert below the grade in question, as scour often occurs through stopping the protection too closely to the bottom of the steep grade.

Cobble gutter with cement joints on grades over 6% and sand or gravel joint filler on grades less than 6% where the volume of flow is not large make probably the best design, as they tend to retard the velocity of flow.

The smooth concrete ditch lining is not usually satisfactory on steep grades but is allowable if the cobble gutter is not available.

Storm Sewers on Hills.—Where it is impossible to divert the water from the surface on long hills a storm-sewer system is sometimes used.

Catch-basin inlets are constructed at intervals of 200 to 400′.

The sizes of pipe are figured for probable run-off in the same manner as for culverts using formulae from Table 46, page 188 with a coefficient c of approximately 0.6. Table 60 gives a rough approximation of the carrying capacity of different sized pipes laid on different grades.

TABLE 60.[1]—APPROXIMATE FLOW CAPACITY IN CUBIC FEET PER SECOND

Value of N = 0.013

Grade, per cent	Capacity of flow of different sized pipes					
	12″	15″	18″	20″	24″	36″
0.5	2.4	4.4	7.5	9.5	16.0	42.0
1.0	3.3	6.3	10.5	14.0	23.0	60.0
1.5	4.2	7.6	13.0	17.0	27.0	75.0
2.0	4.8	8.8	15.0	19.0	31.0	86.0
3.0	5.8	11.0	18.0	24.0	39.0	105.0
4.0	6.5	13.0	22.0	27.0	46.0	122.0
5.0	7.3	14.0	24.0	30.0	51.0	137.0
6.0	8.1	15.0	26.0	33.0	56.0	150.0
7.0	8.8	16.0	27.0	35.0	60.0	162.0
8.0	9.5	17.0	28.0	38.0	65.0	173.0

[1] Computed from diagram in Ogden's "Sewer Design."

Figures 105 and 105*A* give typical catch-basin and simple manhole designs for a sewer.

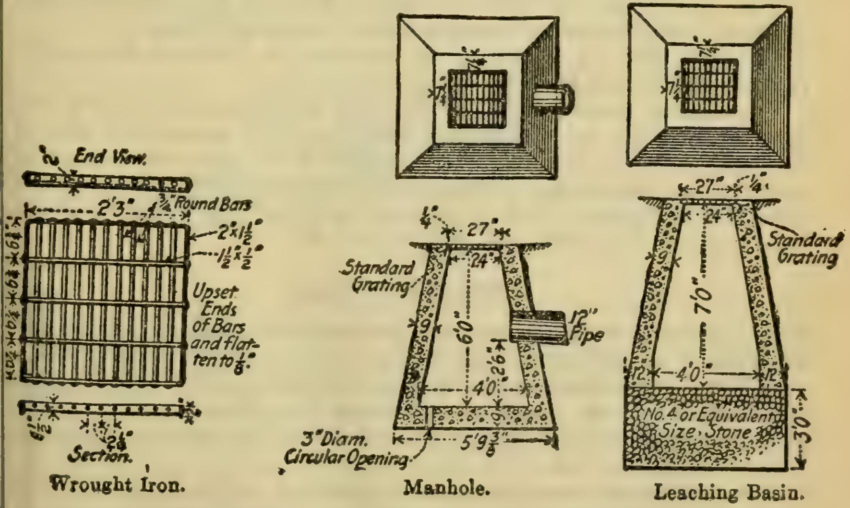


FIG. 105.—Drop inlets and catch basins.

Minimum permissible storm-sewer grades to insure against clogging are given in Table 61.

TABLE 61.—MINIMUM GRADES FOR STORM SEWERS TO PREVENT OBJECTIONABLE CLOGGING

Diameter of pipe, inches	Minimum permissible grade, per cent[a]
12	0.34
15	0.24
18	0.18
24	0.12
30	0.09
36	0.07
42	0.055
48	0.045

[a] Velocity of flow, half full = 2.5′ per second.

Driveway Culverts.—Culverts under drives cause more drainage troubles than any other feature, as they are usually constructed by the property owner instead of being included in the road contract.

It is an amusing fact that private farm bridges over streams or road ditches are notoriously small. Each owner seems to think that water will get under his drive in a small, cheap structure, and the same man who says that a road structure is too small will build a bridge or driveway sluice just below this structure that he has been kicking about and make it from one-tenth to one-half as large as the main drainage structure unless he is prevented by law which is enforced by highway officials.

The size of the structures should be fixed on the road plan and designed from the same standpoint as a culvert or bridge.

Cheaper types of structure are suitable, as they can be readily replaced without tearing up the pavement.

Corrugated metal pipe, vitrified tile, or reinforced-concrete tile are suitable, but no matter how little water is carried the size of driveway culvert should not be less than a 12″ pipe on account of maintenance difficulties. These culverts are properly placed in the ditch line at normal ditch grade and, as a rule, 12′ length is about the minimum that will be at all satisfactory.

UNDERDRAINAGE

The purpose of underdrains on hard-surfaced roads is to intercept the ground water before it reaches and softens the subgrade. On a side-hill road the drain is usually placed under the ditch on the uphill side (see Fig. 106, position 1), where the greatest depth can be obtained with the least excavation and where the water is caught as it flows out of the hill.

Some engineers place the drain in position 2 (Fig. 106), but this requires more excavation for the same depth and for side seepage is

not so effective. The usual depth for drains is 3 to 4 ft. below the surface.

Where the road is on a descending grade, the water will flow out of the hill directly under the stone and the drain is placed as in Fig. 107,

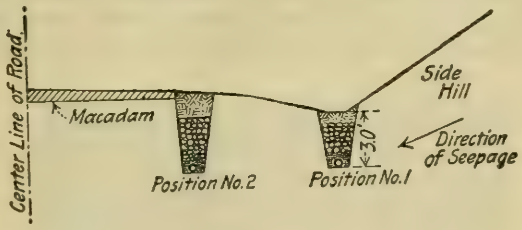


FIG. 106.

position 1, or two drains are built in position 2. Position 1 is the usual practice, being cheaper and more effective.

Two side drains are effective. In case the throat becomes clogged, a side drain can be taken up without disturbing the macadam. This rarely occurs in a center drain, as it is better protected than those in position 2 and in case the center drain does clog, side drains can be constructed at any time.

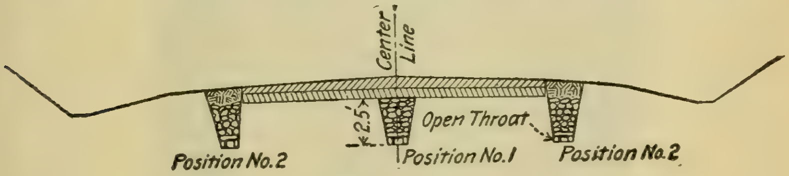


FIG. 107.

There are two kinds of drain in general use (Fig. 108).

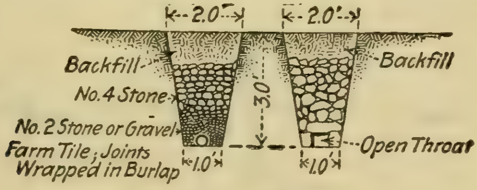


FIG. 108.

No. 1 is built entirely of stone with an open throat roughly laid as shown; it is satisfactory in water-bearing strata of gravelly loam or clay, but does not work so well in quicksand, which is liable to fill it up. It is generally cheaper, however, than No. 2.

No. 2 is built of porous farm tile or vitrified tile of a suitable size (usually 3 to 6″) with open joints, wrapped with a double or triple layer of burlap; the pipe is surrounded and covered with clean gravel or ¾″ crushed stone to a depth of 6″, the remaining depth of the trench being filled with large stone. If this drain has a good fall and the outlet is kept free, it will rarely clog even in bad quicksand.

The following method has been successfully used to prevent the outlet from clogging; after being brought out from under the macadam, the drain is continued under and across the ditch line; then, keeping outside the ditch line, and using a slightly smaller gradient than that of the open ditch, the tile is continued down the hill until it reaches a point 8 or 9″ below the ditch grade. Here it is turned into the open ditch through a small concrete headwall and what little

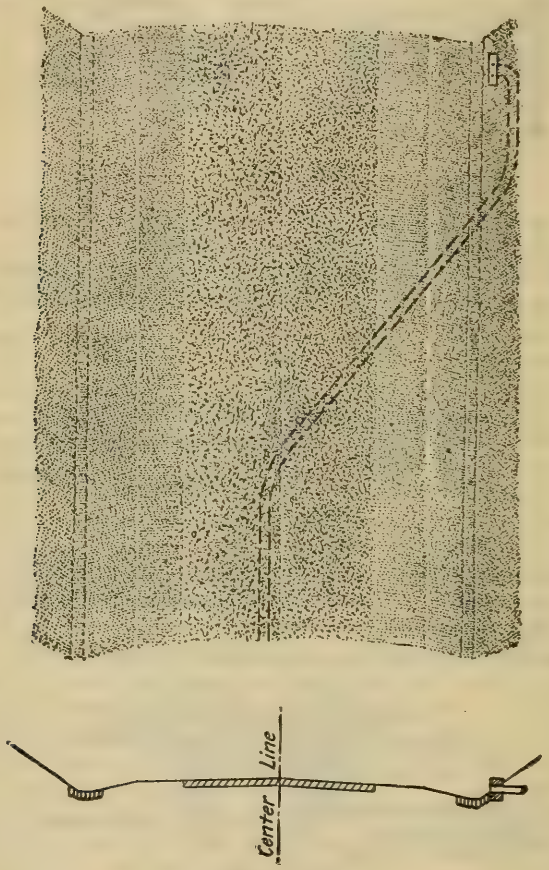


FIG. 109.

material it tends to deposit is washed down the ditch by the surface water (see Fig. 109). The lowest rate of grade advisable for underdrains is 3″ per 100′.

Summary of Chapter.—The present bridge situation demands attention, as even in the richer states it is often lagging behind the improvement of the roads. The separation of bridge and highway funds and the lack of central control often result in the ridiculous situation of a modern road limited in use by antiquated bridges.

Road pavements can be strengthened from year to year by increasing their thickness and by the construction of better surfaces

on top of existing improvements, but structures must be rebuilt entire to increase their strength, and for this reason more foresight in regard to future traffic must be exercised in their design. A liberal allowance for increased loads is desirable. Liberality in size of waterway for culverts is also good policy, as it adds only slightly to the cost and materially decreases the difficulties of maintenance.

The design of drainage must be complete and reasonable, and if the existing scheme is not feasible it should be changed regardless of lawsuits as, whenever an improvement is made, it is always cheaper to correct mistakes at that time than it will be at a later date, as every year's use fixes the channels more firmly.

The selection of type and utilization of parts of existing structures offer the greatest chances for reasonable economy in culvert and bridge design.

CHAPTER V

EARTH, SAND-CLAY, GRAVEL, AND MISCELLANEOUS LOW-TYPE ROADS

Introduction.—Roads of the type discussed in this chapter form the groundwork of future high-class pavements and represent the greater percentage of mileage of roads in this country see page 42. They are entitled to more engineering supervision than they have received in the past; that is, they should be improved by a series of well-thought-out related steps of progressive improvement (page 2).

These types of construction are the initial steps in final road. improvements and serve gradually to pull traffic "out of the mud." They are the only types which can be reasonably built in sparsely settled pioneer districts or agricultural districts of low assessed valuation. Earth and sand-clay roads can, however, be classed only as temporary makeshifts under adverse weather conditions (5 months in the year) on account of softening in wet weather. Gravel roads serve very well as a final stage of improvement for local roads carrying light traffic, provided they are made thick enough to handle 2½-ton trucks the year round. Maximum traffic volumes for the gravel type are discussed on page 353 and for all types of road have been indicated in a broad general way in Chap. I (p. 6).

The following table from Agg's "Construction of Roads and Pavements" reinforces the discussion of traffic limits for the low-type roads. It can be readily seen that these types are suitable for a large percentage of the road improvements in the United States (1926).

Table 62.—Average Daily Traffic Limits in Massachusetts

Table showing results of observations of traffic on different types of road surfaces in Massachusetts. Standard road, 15 ft. in width; gravel or waterbound macadam, 5 or 6 in. in thickness, with adequate drainage and proper foundation, with 3-ft. gravel shoulder on each side.

Type of Surface	Light Teams, Carriages, Wagons	Heavy Teams, One-horse	Heavy Teams, two or more Horses	Automobiles
A good gravel road will wear reasonably well and be economical with..........	50–75	25–30	10–15	50 to 75
Needs to be oiled with.....	50–75	25–30	10–15	Over 75
Oiled gravel, fairly good, heavy cold oil, ½ gal. to the sq. yd. applied annually with....................	75–100	30–50	20	500 to 700 or more
Waterbound macadam will stand with................	175–200	175–200	60–80	Not over 50 at high speed
Cold oil or tar will prove serviceable on such macadam with.................	175–200	175–200	60–80	50–500
Macadam will then stand, but the stone wears, of course, with...............	175–200	175–200	60–80	500 or more
*Waterbound macadam with hot asphaltic oil blanket will be economical with....	100–150	50–75	25–30	1500 and more with fewer teams
And stand at least.........	....	....	....	50 trucks
But will crumble and perhaps fail with over........ (On narrow tires, ice, farm and wood teams, etc.)	150	75	30	
*Waterbound macadam with a good surface coating of tar (½ gal. to the sq. yd.) will stand with........... (But requires to be recoated annually with ¼ gal. of tar per sq. yd.)	100–150	50–75	25–30	1500 or more

It is assumed that all road surfaces are kept constantly patched, that before applying bitumen the road surface is cleaned and patched, and the bitumen covered with pea stone and sand or gravel and kept covered so that it never picks up.

* Authors' Note.—One coat penetration bituminous macadam will stand any number of light autos and more steel tire or truck traffic than shown above, because it takes the wear more directly and has no blanket coat which crumbles under such traffic.

EARTH ROADS

Rut Roads.—The simplest form of road is the so-called rut road used in the arid regions of New Mexico and the Southwest. They are constructed by clearing the right of way of brush and then cutting two shallow parallel ruts in the surface vegetation or soil crust by means of two cutting irons gaged to fit the ordinary wagon track. A wagon trail of this kind can be constructed for $10 to $30 per mile, can be used by autos with fair comfort at speeds up to 15 m.p.h., and on the flat mesas of this district are more lasting and satisfactory than the ordinary turnpiked section, as so little rain falls that an elevated fill grade does not consolidate and is

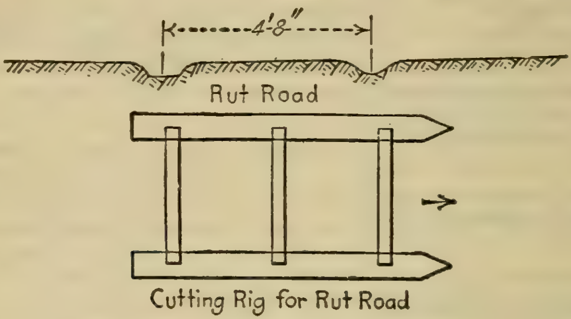


FIG. 110.—"Rut roads."

worse than useless for traffic. On these rut roads any rain storms that occur wash the coarser particles of the soil into the ruts and gradually an armored track is formed below the general elevation of the mesa. No drainage structures are necessary where construction of this type is adopted.

Earth Roads.—The same principles of grade, section, and drainage apply to this class of road as to the higher types except that the surface ditches are generally made slightly deeper and more care is taken with the underdrainage; this is necessary as the earth road becomes more easily saturated with water than types which are sealed over on the surface. If the natural soil is good road material, such as gravel, disintegrated rock, hardpan, or sandy loam, this type of construction carefully graded, drained, and shaped by blader finish and maintained by dragging makes a satisfactory road for light traffic. Their cost depends on the amount of grading required and the methods that can be used. The cost of drainage culverts, incidentals, etc. will vary, but will run about $600 per mile for good work.

Simple blade-machine turnpiking, where the dirt from the ditches made the center fill, cost (in districts similar to Wyoming 1914–1915) about $150 per mile. The same work at present (1918) is bid off for about $200 per mile. A fair relative price for first-class work of this kind, including drainage and incidentals, can be placed at $600 to $800 per mile.

In rolling country requiring grade reductions by cut and fill and wagon haul, a fair relative price, including drainage and incidentals, is approximately \$2000 to \$4000, where no rock is encountered.

In mountain-road work where the excavation runs anywhere from 1000 to 30,000 cu. yd. per mile with a large percentage of rock the

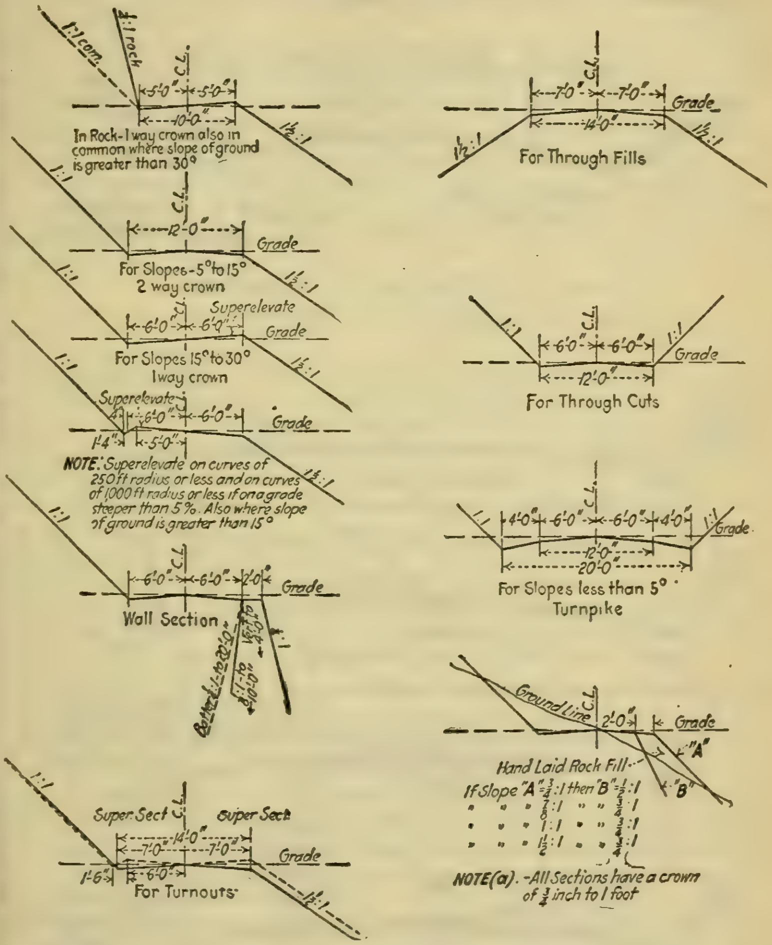


FIG. 111.—U. S. Bureau of Public Roads standard mountain earth road sections.

cost will run anywhere from \$1000 to \$25,000 per mile. A fair average for such conditions is \$5000 to \$8000 per mile (1922 cost conditions).

As previously stated, it is entirely a matter of required grading.

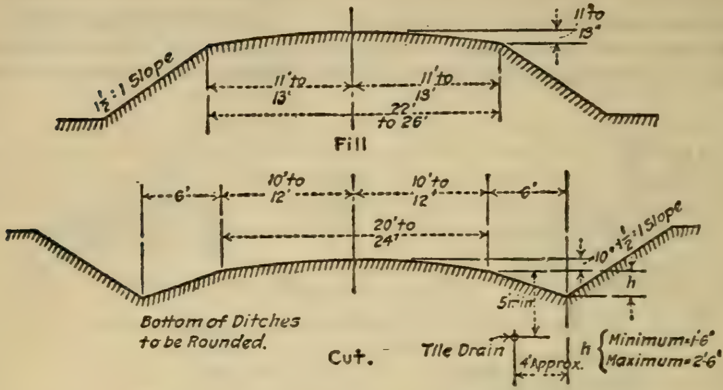


FIG. 112.—Iowa earth road sections.

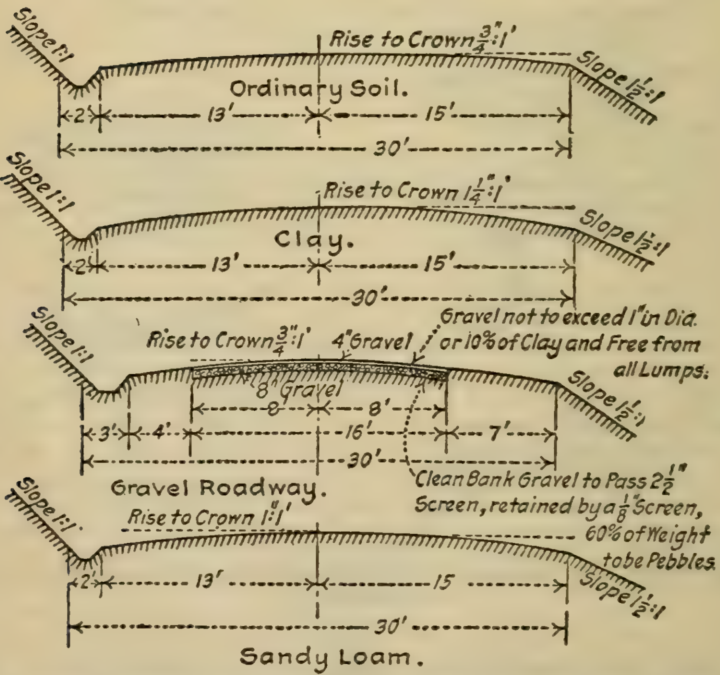


FIG. 113.—Typical earth and light gravel road sections, State of Pennsylvania.

Current practice in earth-road sections is shown in the following figures and also in Chap. III (pp. 146 to 171).

Mountain roads.......................... Fig. 111 (p. 345).
Iowa standards.......................... Fig. 112 (p. 346).
Pennsylvania standards...................... Fig. 113 (p. 346).

Current practice in grading and finishing is given in the typical specifications (p. 1444).

Earth-road maintenance is discussed in Chap. VII. The cost ranges from $20 to $200 per mile per year and for ordinary conditions probably averages about $50 to $100. Where it rises above these amounts a better grade of surface is generally constructed.

Where the soil is not a good road material the surface is improved, by artificial mixtures of selected soil or by surfacing with gravel, chert, disintegrated granite, slag, shell cinders etc.—in fact, any local material that gives body to the surface and prevents softening during the wet season.

SAND-CLAY ROADS

A poor earth road can be very materially improved by the so-called sand-clay surfacings. A well-selected proportioning of sand and clay increases the resistance of a poor earth road both to traffic wear and to softening due to moisture. A sand-clay surface cannot, of course, be considered as a satisfactory all-year-round road for heavy load, but it is the easiest and cheapest means of increasing the ease and comfort of travel for a large part of the year, and this type of road has had considerable popular approval, particularly in the southern states. It is economically justified for light volume of traffic in financially poor districts where good road gravel is not available. Sand-clay construction is not advised in the northern states where gravel is available.

Typical sand-clay crowns, widths, and thicknesses are shown in Fig. 114 and in Chap. III (pp. 147 and 148).

The cost of surfacing with sand clay varies, as any form of construction, with labor, length of haul, cost of materials, etc., but generally adds from 15 to 35 cts. per square yard to the cost of an earth road. A fair comparative figure would add $1500 to $2500 per mile for a 16′ width over earth roads and costs about the same as earth-road maintenance. Specifications for sand clay are given on page 351.

Proportioning of Soil Mixture.—Where the natural soil is clay the resisting power of the surface during wet weather can be increased by the addition of sand. Where the natural soil is deep sand the surface can be made firm and resilient by the addition of clay. The so-called sand-clay treatment aims to provide a surface layer of mixed sand and clay about 10 to 12″ deep (see Fig. 114, Alabama Standards), in which the sand forms the body and the clay just fills the voids in the sand and acts as a binder. It can be readily seen that different materials will require different proportioning of the sand and clay. The only sure way to get the best

results is by experiment on the road during construction, but to give an idea of the approximate proportioning the following list of recommended mixes is taken from the "Good Roads Year Book" of the American Highway Association, 1917.

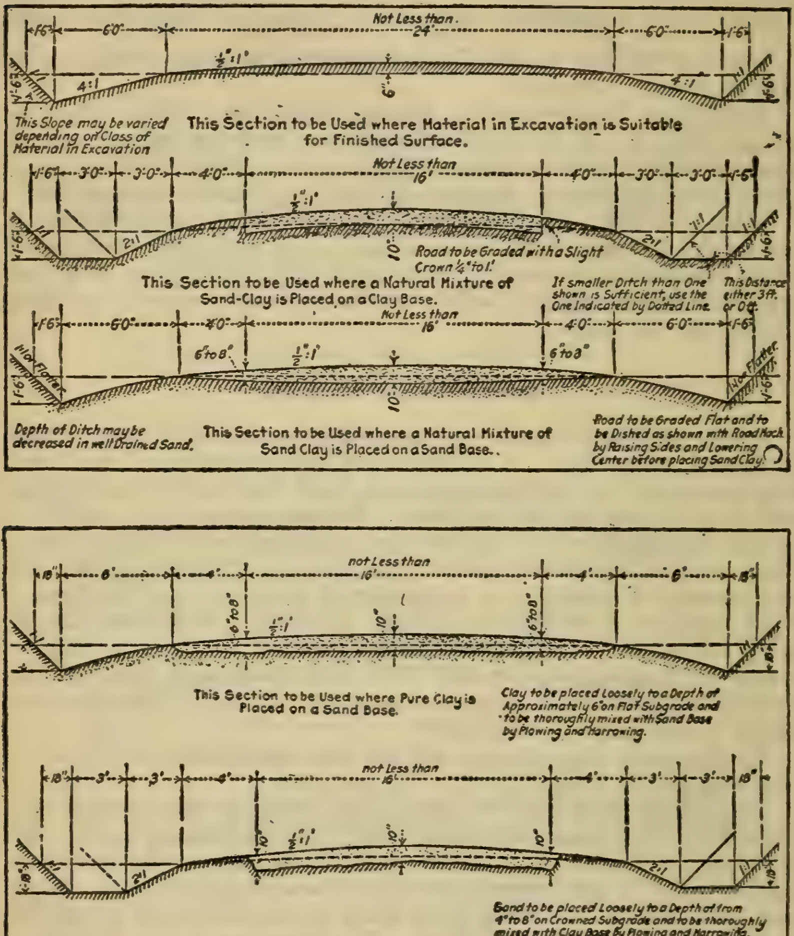


FIG. 114.—Typical sand clay road, State of Alabama.

"The grains of which sand is composed are usually hard and tough and able to resist abrasion if held securely in place. In an asphalt pavement they are held by the asphalt and a wearing surface of great resistance to abrasion results. In a sand-clay road they are bound together by clay in a less firm manner but one giving excellent results on well-drained roads carrying light traffic. The aim of the builder of such a road is to employ just enough of the stickiest clay at his command to fill the pores of the sand and to mix these materials together so thoroughly that there are neither lumps of clay nor pockets of loose sand left in the surfacing. This gives the maximum amount of hard sand to carry the traffic and the minimum amount

of clay to bind it. More sand makes a less durable road and more clay makes one which becomes soft more rapidly when wet.

"There is a great difference in the value of different clays for such work. Some of them become dough-like when mixed with a certain amount of water and can be molded into objects which retain their shape after drying. If these molded objects are immersed in water they will retain their form for a long time. These varieties are called 'plastic clays' and the most plastic are called 'ball clays.' Other varieties fall to pieces more or less quickly when wet, as quicklime does, and they are therefore called 'slaking clays.' They are more easily mixed with sand than the plastic clays, but they have much less binding power and a road built with them is less durable when dry and more easily rutted when wet. The amount of clay to be used can be determined by a simple field test described as follows by Andrew P. Anderson:

" 'From typical samples of each of the available clays, test mixtures, varying by one-half part, are made with the sand so that each clay is represented by a set of mixtures ranging by successive steps from one part sand and three parts clay to four parts sand and one part clay. These are worked up with water into a putty-like mass and from each mix two equal quantities are taken and rolled between the palms of the hands into reasonably true spheres, labeled, and placed in the sun to dry. When thoroughly baked, a set of spheres representing any one clay is placed in a flat pan or dish and enough water poured gently into the pan to cover them, care being taken not to pour the water directly on the samples. Some samples will begin to disintegrate immediately. Those breaking down most slowly contain most nearly the proper proportion of sand and clay for the particular materials. The relative binding power of the various clays may then be determined by comparing the hardness and resistance to abrasion of the various dry samples having the correct proportion of sand and clay, as determined by the water tests.' "

"In February, 1917, representatives of 21 state highway departments of the U. S. Office of Public Roads recommended the following mixtures for hard, medium, and soft classes of sand-clay roads.

"*Hard Class.*—Clay, 9 to 15%; silt, 5 to 15%; total sand, 65 to 80%; sand retained on a 60-mesh sieve, 45 to 60%.

"*Medium Class.*—Clay, 15 to 25%; silt, 10 to 20%; total sand, 60 to 70%; sand retained on a 60-mesh sieve, 30 to 45%.

"*Soft Class.*—Clay, 10 to 25%; silt, 10 to 20%; total sand, 55 to 80%; sand retained on a 60-mesh sieve, 15 to 30%.

"By clay is meant material separated by subsidence through water and possessing plastic or adhesive properties; it is generally below 0.01 mm. in diameter. By silt is meant the fine material other than clay which passes a 200-mesh sieve and is generally from 0.07 to 0.01 mm. in diameter. By sand is meant the hard material which passes a 10-mesh and is retained on a 200-mesh sieve, and is generally from 1.85 to 0.07 mm. in diameter."

The larger part of the following explanation of the construction of sand-clay roads was prepared by W. S. Keller, State Engineer of Alabama, where many miles of sand-clay roads have been built and are giving good satisfaction.

"Every farmer who lives in a section of country where both sand and clay are prevalent is more than likely traveling over a section of natural sand-clay road but is ignorant of the fact. He can call to mind some particular spot on the road he travels though it may not be more than 100′ in length, that is always good and rarely requires the attention of the road hands. Good drainage will be noticed at this place, and if he takes the trouble to investigate he will find that a good mixture of sand and clay form the wearing surface. If this 100′ of road is always good, then the entire road can be made like it, provided man will take advantage of the lesson taught by nature and grade the road so that the drainage will be good and surface the balance of the road with the same material. If it is not possible to find the ready-mixed surfacing material convenient to the road, it may be possible to find the two ingredients in close proximity. In case the road after grading shows an excess of sand, clay should be added, or in case clay predominates, sand should be added to produce good results. There are four general ways in which sand-clay roads may be built:

"1. Ready-mixed sand and clay placed on clay, sand, or ordinary foundation.

"2. Sand and clay placed on soil foundation and mixed.

"3. Clay hauled on a sand foundation and mixed with the sand.

"4. Sand hauled on a clay foundation and mixed with clay. Taking up the various methods in order:

"1. A natural mixture of sand and clay can often be found where the two materials are found separate. The most important point is to know the natural mixture when seen. The very best guide to this is to find a natural piece of good road. A sample from the best of this section will, by comparison, indicate what is required, close to the road to be surfaced. This natural mixture of sand and clay can be noticed where red clay and sand crop out, usually well up in the hills, having ditches and cuts the appearance of red sandstone. A good stratum of well-mixed sand and clay will stand perpendicular in cuts and ditches, resisting erosion almost as well as sandstone. A test of the best natural sand-clay mixtures will show the sand forms about 70% of the whole. The test is very simple. Take an ordinary medicine glass, measure 2 oz. of the mixture into the glass, and wash out the clay. Dry the remaining sand and measure again on the medicine glass. The loss will be the amount of clay originally contained in the mass.

"Before placing any sand clay on the road, the road should be graded to the desired width. The surface of the graded road should be flat or slightly convex. The sand clay should be put on from 8 to 12″ in thickness, depending on the character of the subgrade or foundation. With a hard clay for foundation, 8″ of sand clay will suffice. If the subgrade is sand, it is well to put on as much as 12″ of the surfacing material. After a few hundred feet of surfacing material has been placed, a grading machine should be run over it to smooth and crown the road surface before the top becomes hard and resists the cutting of the blade. It is a good plan to turn the blade of the machine so as to trim the edges of the surface part, discharging the excess sand and clay onto the earth shoulders. After one round-trip with the blade turned out, the remaining dress work with the machine should be with the blade turned in, with the exception of one trip down the center of road with the blade at right angles to the axis of the road for the purposes of distributing any excess of material left in the center.

"After the machine work, it is well to follow with a drag, which smooths any rough places left by the machine and leaves the road with a smooth, even surface. A sand-clay road, unlike other roads, cannot be finished in a short space of time. It can be left in an apparently finished condition with a hard, smooth surface, but it will be found on close examination that the hard surface is, in reality, only a crust, below which there are several inches of loose material. After the first hard rain the crust softens, the road becomes bad, and the work appears to be a failure. This, however, is just what is needed to make it eventually good. After the surface has dried until the mass is in a plastic state, it should be dragged until the surface is once more smooth, with proper crown, and should be kept this way by dragging at least once a day until the sun has baked it hard and firm. The mistake of keeping traffic off during this process of resetting should not be made. The continuous tamping of the wheels of wagons and hoofs of horses is just what is needed to compact the sand clay into a homogeneous mass. The ordinary roller is not very effective in this work, but corrugated rollers have given excellent results. One type which is widely used has 18 cast-iron wheels weighing 300 lb. each, which compress the bottom of the mixture first. As the material becomes more and more compact the wheels ride higher and finally the surface is so hard that the roller does not sink into it it all. A drag is an indispensable machine in the construction of any kind of sand-clay road.

"2. Sand and clay placed on a soil foundation and mixed. This is necessary where the old road had neither a sand nor clay foundation and it is impossible to find the two ingredients ready mixed, but possible to get both in separate state near at hand. The clay should first be placed on the road to a depth of 4″ and the required width. It is not wise to place more than a few hundred lineal feet of clay before the sand is hauled, as the clay rapidly hardens and makes the mixing process difficult. After, say, 400′ of clay have been placed, the clay should be broken by means of a plow and harrow, if it has become hard, and sand to a depth of 6″ placed on it. This should be plowed and harrowed in thoroughly. This is best done immediately after a rain, as the two can be more satisfactorily mixed. The traffic aids the mixing and should be encouraged on the road. After the mass appears

to be well mixed, the road should be properly shaped, as previously explained. The road should be given watchful attention and, should sand or mud holes appear, a second plowing and mixing should be given it.

"3. Clay hauled on a sand foundation and mixed with sand. The mixing process is similar to that described under the second head. It is only necessary to add that, as the foundation is sand, a little more clay will be necessary than where the foundation is of clay or soil.

"4. Sand hauled on a clay foundation and mixed with clay. The clay foundation should be plowed to a depth of 4" and harrowed with a disk or tooth harrow until the lumps are thoroughly broken or pulverized. Sand should then be added to a depth of 6" and mixed as before described.

"Sand and clay can be mixed best when wet, but as most road construction is done in the summer months, it is necessary to do most of the mixing dry and keep the road in shape after the first two or three rains, while the passing wagons and vehicles give the road final wet mixing. A sand-clay road is the cheapest road to maintain, since it can be repaired with its own material. with a drag or grading machine, ruts can be filled with material scraped from the edges, whereas on gravel or macadam roads this is not possible. The repairing of these roads can be done almost exclusively with the drag, only enough hand work being required to keep the gutters open and the growth of weeds cut on the shoulders. Holes are repaired by adding more sand clay and when many of them appear, fresh sand clay should be spread over the surface of the road. If the road gets into really bad condition, the roadbed should be plowed up, reshaped, and fresh sand clay added. This is unnecessary where the road is maintained properly and the travel is not too heavy for this type of construction."

Top Soil or Sand-clay Surface (Alabama State Specifications)

"**Description.**—Upon the subgrade, prepared as hereinbefore specified, shall be constructed a top soil or sand-clay surface of the cross-section and compacted thickness shown on the plans.

"**Surfacing Material.**—The surfacing material shall consist of top soil or natural sand clay obtained from the fields or pits designated by the engineer, and as near the right of way as practicable, or, in the event that it is impracticable to secure suitable top soil or natural-mixed sand clay, the surface shall consist of an artificial mixture of sand and clay, the materials for which artificial mixture shall be obtained from places designated by the engineer. Before any surfacing material is used it shall first have been approved by the engineer. The surfacing material shall be free from trash or other foreign matter and contain no stones or boulders that would fail to pass a 1½" ring. Should any such non-road-building material be placed on the road, it shall be removed by the contractor at his own expense.

"The fields or pits from which the surfacing material is to be obtained will be furnished by the county free of charge to the contractor, but the contractor must provide and maintain at his own expense all necessary roads for hauling the surfacing material to the road.

"**Construction Methods.** *Case* 1.—Where the surfacing material consists of either top soil or natural sand clay that has been approved for use without the admixture of any other material, it shall be evenly spread on the subgrade to such depth that, when compacted, the surface will have the compacted thickness shown on the plans. The material shall be dumped on the subgrade in longitudinal rows containing not more than ⅓ cu. yd. to 10 lineal ft. and the number of rows shall be such that when the material is spread the desired cross-section and thickness of surface will be obtained. After sufficient material has been dumped in this way for 100 to 200' of road surface, and before any part of the rows has commenced to pack, it shall be spread approximately to the required cross-section and harrowed to secure uniformity. The spreading may be done by hand or with a road machine in the following manner: (1) The machine shall be run over the road with the blade set so as to scrape off the tops of the piles and fill in the spaces between. (2) The outside edges shall be gone over with the blade set so as to pull the top soil or sand clay toward the center. (3) The grading machine shall be run over the shoulders so as to pull the shoulder material up against the surfacing material and thus bring the entire road surface approximately to the required cross-section. The surface portion of the road shall then be harrowed with either a tooth or disc harrow until uniform density is secured, after which the road shall be brought to the required cross-section and so maintained until accepted. The shaping or reshaping of the surface shall be undertaken only when the weather conditions are such that the loosened surfacing or shoulder material will be readily compacted by traffic to form a well-bonded surface.

"*Case 2.*—When the surfacing material is to consist of an artificial mixture of sand and clay, made by mixing the material of the roadbed with sand or clay from some other source, the construction shall proceed in the following manner:

"1. The surface of the roadbed shall be thoroughly loosened by plowing and harrowing to a depth of from 4 to 8″, according to the nature of the two materials to be mixed, and as the engineer may direct.

"2. The material to be added shall be dumped and spread in the manner described for Case 1.

"3. The added material shall be thoroughly mixed and incorporated with the material of the roadbed. The mixing shall be done by means of plowing and harrowing and shall continue until the engineer is satisfied that the two materials are thoroughly mixed in proper proportion. A part of this mixing shall be done when the road is wet so that the surface will be puddled.

"4. If, after mixing the two materials as described above, a deficiency of the added material is apparent at any point, such deficiency shall be immediately corrected by spreading more of the material at that point and continuing the mixing as above described.

"5. After the mixing is complete, as above specified, the road shall be shaped and maintained as provided in Case 1, except that wherever a poor mixture is observed it shall be corrected by additional mixing or by adding necessary material and mixing.

"*Case 3.*—When the surfacing material is to consist of an artificial mixture of sand and clay, both of which materials are to be obtained from without the road, the construction shall proceed in the following manner:

"1. The materials shall be spread in successive layers on the road and mixed in place. The engineer will determine the order in which the two materials shall be spread, as well as the depth of layer for each material.

"2. The dumping and spreading of the materials shall be done as specified for Case 1.

"3. The mixing of the two materials and the maintaining of the road shall be done as specified for Case 2.

"**Basis of Payment.**—The contract price per cubic yard for top soil or natural sand-clay surfacing material shall be full compensation for loosening, loading, spreading, and harrowing, and for hauling the surfacing material 1 mile or less, as well as for shaping and maintaining the surface true to cross-section until the road is accepted. In the case of an artificially mixed surface the materials brought onto the road will be paid for at the contract price per cubic yard for top soil or natural sand-clay surfacing material, which will include all the items mentioned above except harrowing, and the contract price per square yard for mixing will be full compensation for all necessary harrowing, plowing, or other mixing. Measurement of all top soil or sand-clay surfacing materials will be made in trucks, wagons, or cars, as it is delivered on the road, except that where the surfacing material is hauled in scrapers or shoveled on to the road it will be measured compacted in place on the road.

"Stripping of surfacing material pits will be paid for at the contract price for common excavation.

"The bid price for overhaul of sand clay will be allowed on all sand-clay materials necessarily hauled a greater distance than 1 mile. The method of determining overhaul will be in all respects similar to that provided for determining overhaul in the case of crushed-stone surfaces."

GRAVEL ROADS

A coarse, well-graded gravel is the most satisfactory material for a cheap year-round road. It gives body to the traveled track, binds well, rides easily, and with a consolidated depth of 8 to 20″ holds all ordinary loads after it is well consolidated. For wheel pressures and depths of metaling see Chap. VI (p. 391).

Cost.—Pit-run gravel varies in cost from 75 cts. to $3.50 per consolidated cubic yard in place, screened gravel from $1.50 to $4 per consolidated cubic yard. Gravel surfacing adds approximately $2000 to $6000 per mile to the cost of an earth road in the same location and a fair comparative price for this type, including

drainage and incidentals, ranges from $4000 to $10,000 per mile (1926 cost conditions). Maintenance is discussed in Chap. VII. The cost has a wide range from $100 to $600, depending on the volume of traffic and degree of perfection of maintenance. As a

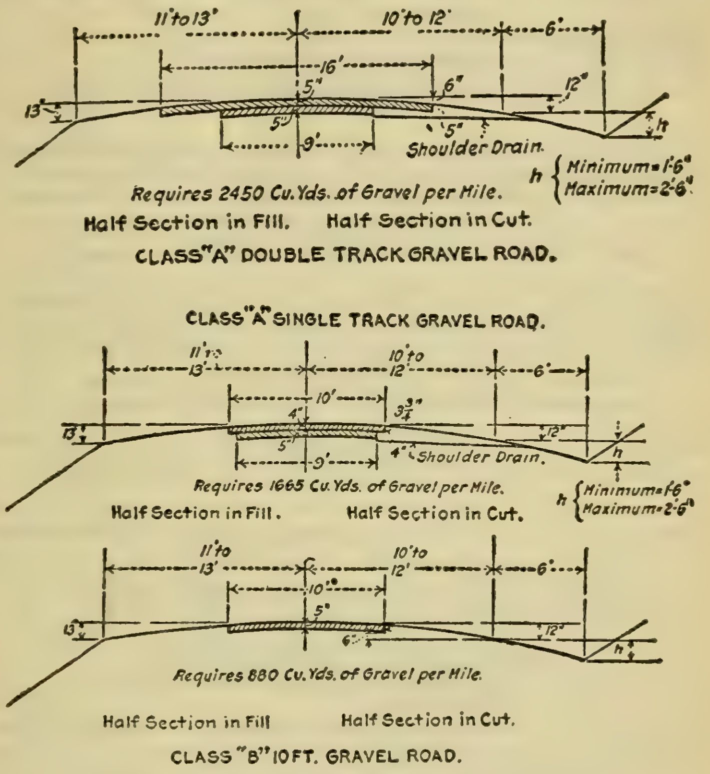


FIG. 115.—Gravel roads State of Iowa.

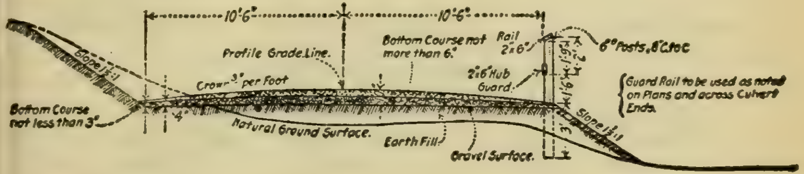


FIG. 116.—New Hampshire gravel road section.

general rule, where the maintenance cost exceeds $400 to $600 per year it is advisable to build a better grade of pavement.

General Suitability.—At the present time 50% of the mileage of surfaced roads in the United States are gravel roads. They are suitable for volumes of traffic up to 350 to 400 vehicles daily.

Beyond this limit they often become rough on account of so-called rhythmic corrugations which are difficult to control. Gravel has been utilized as a temporary expedient up to 2000 to 3000 vehicles daily, but it cannot be advised for any such amount of traffic. Oiling with a light cold asphaltic oil or cold tar is resorted to under

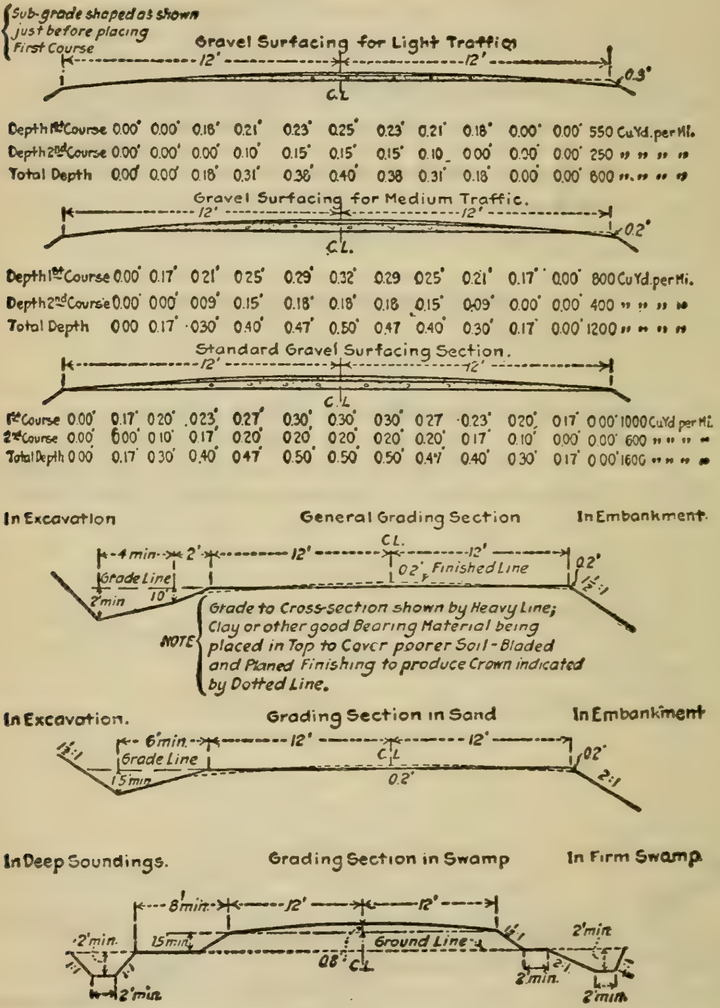


FIG. 117.—Typical gravel road section, State of Minnesota.

moderately heavy automobile traffic. No gravel road should be oiled till at least a year old, so that it may be completely consolidated and firmly bound. The surface must be well cleaned of excess fine dust and the oil applied in two or three successive light coats of approximately ⅛ gal. per square yard at intervals of 2 or 3 months. It takes more than one application to give even moder-

ately good results, as the clay and loam in the road tend to prevent the formation of a good bond between the oil and gravel, but if persistent treatment is adopted this method increases the power of gravel roads to withstand touring-car traffic, but, of course, does not increase their structural strength or make them suitable for heavy-unit freight hauling. An official report on page 360 illustrates the economic use of gravel as compared with higher-priced pavements for special conditions even on primary state highways. Figures 115 to 117 and Chap. III (p. 147) show usual practice. Table 74 (p. 391) gives required depths for different loads on different soils.

Construction Essentials.—Gravel roads are hard to consolidate quickly and need careful and continuous attention to prevent the formation of ruts, holes, or humps. They cannot be built by merely dumping loose gravel on the road and then hoping that traffic will put it in shape. A large mileage has been built on this principle and the results are shameful. A successful gravel road requires careful selection of the gravel, careful spreading, careful consolidation, and constant maintenance. Current practice is shown in typical Specifications (pp. 357 and 1452); the essential features will be summarized at this point.

Size of Gravel

Gravels suitable for road work are widely distributed over the country. They occur in bank deposits and in stream beds. The prime requisite of a gravel for foundation courses is that it contain a large percentage of coarse pebbles to give body and distribute the wheel loads. The prime requisite for a surfacing gravel is hardness of the stone and well-graded coarse and fine particles which will take the wear evenly and bond well. Pit-run gravel varies greatly as to size and composition even in a single pit, and for this reason no definite limits can be well set for the proportion of sizing. In general, it can be said that for foundation courses any coarse gravel, which when screened through a ¼″ mesh contains less material passing the screen than retained on it, can be successfully manipulated without screening to remove the excess sand. In some localities this limit is not feasible on account of excessive fine material and the limit of fine material passing a ⅛″ mesh is placed at 60%, but, in reality, a gravel of this fineness does not produce satisfactory results and a road on which it is used becomes more nearly a sand-clay construction than a gravel type. For a top course the large stone above 1½″ in size should be screened out, and if pit-run gravel is used the sand passing the ¼″ mesh should not exceed 40% of the volume. The most satisfactory top is a screened gravel, but this adds materially to the cost. Where screened gravel is used ½ to 3″ is satisfactory size for the bottom course and ½ to 1½″ for the top course with a light surface wearing coat of sand ranging from pea size up to ½″ in diameter.[1]

[1] There is some tendency to reduce maximum size of top-course gravel to 1¼ or even 1″.

The following specification has been recommended by the Committee on Materials of the A.S.C.E.

"Two mixtures of gravel, sand, and clay shall be used, hereinafter designated in these specifications as No. 1 product (for top course) and No. 2 product (for middle and bottom courses).

"Number 1 product shall consist of a mixture of gravel, sand, and clay, with the proportions of the various sizes as follows: all to pass a 1½" screen and to have at least 60 and not more than 75 % retained on a ¼" screen; at least 25 and not more than 75 % of the total coarse aggregate (material over ¼" in size) to be retained on a ¾" screen; at least 65 and not more than 85 % of the total fine aggregate (material under ¼" in size) to be retained on a 200-mesh sieve.

"Number 2 product shall consist of a mixture of gravel, sand, and clay, with the proportions of the various sizes as follows: all to pass a 2½" screen and to have at least 60 and not more than 75 % of the total coarse aggregate to be retained on a 1" screen, at least 65 and not more than 85 % of the total fine aggregate to be retained on a 200-mesh sieve."

Bonding Properties.—Clean gravel will not bond well. A small percentage of clay, loam, or lime dust is desirable and necessary. This per cent ranges from 10 to 20%. For bottom course, pit-run gravel which contains over 20% of clay or loam should not be used; from 10 to 15% gives the best results. For top course, 10% is about the maximum clay or loam allowable, particularly if it is to be treated with bitumen. Many so-called cementitious gravels of lime rock contain or produce under traffic a first-class rock-dust binder of the highest grade. Clay or loam can be added to a clean gravel by mixing at the pit or by placing a thin layer of such material over the gravel as spread on the road and mixing it with the course during consolidation.

Spreading.—Gravel must be uniformly spread; there are two general methods—the trench spread (Fig. 115) and the feather-edge spread (Figs. 116 and 117). The trench spread is not so likely to break down at the edges as the feather-edge, but this can be remedied by a wider spread where the feather-edge method is used. In either case the depth should be uniform and the surface properly crowned. Gravel should not be dumped in piles; it should be spread along in windrows or in sheets with Manger spreader and the spreading finished by shoveling, raking, or by road machine blade scrapers. If pit-run gravel is used, the course should be harrowed to distribute the sizes uniformly. The ratio of compacted to loose depth is approximately 1.2 or 1.25. that is, a loose depth of 8" will compact to about 6½". If screened gravel is used, the filler should be added before the course is rolled.

Consolidation.—Consolidation is the hardest feature of pit-run gravel construction. Detail methods are described under Gravel Foundations (p. 432). A combination of traffic and roller consolidation while the gravel is moist gives the best and quickest consolidation, although traffic alone will put it down firmly if given time and the shape is kept intact by constant dragging with a hone or road machine. The Minnesota Specifications show the method employed where a road roller is not used.

Minnesota Specifications

Graveling

"**Description.**—Graveling shall be construed to mean all surfacing with pit-run gravel, screened gravel, or crushed rock, or crushed rock screenings built in two or more successive courses.

"**Materials.**—All materials shall be of a quality approved by the engineer and shall be the best obtainable from the specified pit or quarry. Materials for the first course shall contain no stone which would be retained on a screen having 2½″ openings. Materials for the second course shall contain no stone which would be retained on a screen having 1″ openings. If available material contains an excess of sand, such excess shall be handled as provided by special specification for each job or project.

"**Subgrade.**—The cross-section of the subgrade shall be shown on the standard cross-section accompanying the plans. Graveling upon a wet muddy roadbed will not be permitted. If the graveling is not done in conjunction with the grading as a part of the same contract, the subgrade for the full length of the job embraced in the graveling contract shall, before being graveled, be dressed by the county to the cross-section above mentioned. Thereafter, the contractor shall keep it dressed to the specified cross-section and free from ruts, waves, and undulations, as part of the graveling contract. If the grading and graveling are performed under the same contract, the preparation of the subgrade shall be performed as part of the grading item and no additional charge will be allowed therefor under the graveling.

"**Loading and Hauling.**—Loading from pits shall be performed in such a manner and by such methods that a uniform grade of materials will not be delivered upon the road. Stone exceeding the sizes specified shall not be loaded. No earth, sod, or any foreign or vegetable matter, nor an excess of sand or clay, will be allowed in the gravel, and care must be taken that strippings be not mixed with the gravel. Any loads taken to the work containing such objectionable materials will be rejected.

"**Dumping and Spreading First Course.**—The first-course material shall be deposited in a uniform ridge on the center line of the road and shall be spread immediately upon the subgrade to a uniform section. This work shall be started at a point on the road nearest the pit or loading place and shall proceed therefrom until the extreme haul in that direction is reached.

"**Shaping and Compacting.**—The resurfacing material shall be shaped, while being compacted under travel by the use of a blade grader, tooth harrow, planer, or other suitable means. Ruts formed by the hauling or by travel shall be dragged full at least once each day, and more frequently if necessary, to prevent cutting through the surfacing material into the subgrade. Holes, waves, and undulations which develop and are not filled by dragging shall be filled by adding more material according to the direction of the engineer. The shaping of the material shall be performed according to the direction of the engineer and shall be continued until the material is well compacted, free from ruts, waves, and undulations, and is made to conform to the cross-section indicated on the standard above mentioned.

"If the material is not sufficiently compacted by the above methods within 20 days after placing, the engineer shall direct the character, amount, and method of applying the binding material necessary to provide a compacted surface, and the contractor shall provide the necessary labor and equipment to perform such additional work at the unit prices submitted for application of the regular surfacing material. The county shall furnish the binding material in the same manner as provided for the regular first- and second-course material.

"**Second Course.**—When the first course is compacted and shaped as specified, to the satisfaction of the engineer, he shall authorize the application of the second-course materials. It shall then be applied, shaped, and compacted by the methods specified for the first course. The work of shaping and compacting shall be continued until the material is well compacted with the surfacing free from ruts, waves, and undulations and conforming to the specified cross-section."

Other Coarse Materials.—The same principles apply to the use of any available local material, such as slag, chert, caliche, disinte-

grated granite, shell, etc., each one of which can be used to advantage in special localities. A specification for chert follows:

CHERT SURFACE (ALABAMA STATE SPECIFICATIONS)

"**Description.**—On the subgrade, prepared as hereinbefore specified, shall be constructed a chert surface of the cross-section and compacted thickness shown on the plans.

"**Chert.**—Before any chert is used in the construction of the road surface, it shall first have been approved by the engineer. In general, the special provisions accompanying the proposal form will indicate the locations from which satisfactory chert may be obtained and also indicate whether crushing and screening of the chert will be required. Any large particle of chert that may be spread on the road, and that would fail to pass a 2″ ring, shall be broken by hammering, or otherwise, before the surface is rolled. Unless otherwise provided in the special provisions, chert quarries will be furnished by the county free of charge to the contractor, but the contractor must provide and maintain roads to such quarries at his own expense.

"**Construction Methods.**—The chert shall be spread on the subgrade to such depth that, when compacted, the surface will have the compacted thickness shown on the plans. It shall be dumped, spread, and rolled in the manner hereinbefore specified for dumping, spreading, and rolling No. 1 and No. 2 crushed stone in the case of crushed-stone surfaces. Where, in the judgment of the engineer, the conditions are such that a well-bonded surface is not secured by rolling as specified above, the contractor shall sprinkle the surface with water while rolling is in progress, and the sprinkling shall be done in such quantity and in such manner as the engineer may direct.

"**Basis of Pavement.**—The contract price per cubic yard for chert for surfacing shall be full compensation for quarrying, crushing, loading, spreading, rolling, sprinkling, hauling the chert 1 mile or less, and maintaining the surface until the road is accepted. Measurement of chert will be made in trucks, wagons, or cars as the chert is delivered. Stripping of chert quarries will be paid for at the contract price for common excavation. The bid price for overhaul of chert will be paid on all chert necessarily hauled a distance greater than 1 mile. The method of determining overhaul will be in all respects similar to that provided for determining overhaul in the case of crushed-stone surfaces."

REPORT ON RHYTHMIC CORRUGATIONS

By George E. Ladd, for U. S. Office of Roads

"**Their Relation to Traffic.**—Gravel roads subject to a traffic of not more than 200 or 300 cars per day remain practically free from corrugations, if occasionally dragged. As soon, however, as traffic reaches 400 to 450 cars per day, corrugations develop very rapidly. In the state of Maine, where tourist traffic is large during summer months, and its rate of increase is well known, the state highway officials can predict almost to a day when corrugations will begin to develop on certain roads. The traffic limitations of gravel roads, in general, are determined by the intensity of maintenance required and by its costs. Sufficient data have not yet been gathered on this subject. A highway engineer's handbook covering the subject of gravel roads states that they are not fit for traffic exceeding 100 cars per day, but in Maine, Connecticut, New Hampshire, and other states they are successfully serving a traffic of from 700 to several thousand cars per day. In Wisconsin, gravel roads are maintained with comparatively smooth surface so that auto travel is comfortable and satisfactory on roads serving from 1800 to 3200 cars per day with a maintenance cost ranging from $280 to $320 per year, or from $600 to $700 per year when the roads are also treated with dust preventives.

"Maintenance costs on gravel roads in various states have been reported to the writer as ranging from $1000 to $3000 per year. No satisfactory analyses of such costs have been made and it is presumed that a considerable portion of them really belong to improvement and reconstruction.

The Relation of Rhythmic Corrugations to Kinds of Gravel

"**Mix and Methods of Construction.**—The fact that these corrugations are so general and occur in all sections of the United States makes it evident that nearly all gravel roads are subject to the development of this nuisance and menace, if they serve sufficient traffic, although the methods of construction and kinds of gravel vary widely. The situation, however, is not hopeless. Several highway officials have expressed the opinion that less corrugation trouble is found where the gravel is angular and where it is composed of highly rounded particles. It is also claimed that where the road is constructed of gravel more uniform in size than pit run, and especially where everything over 1″ is excluded, that corrugations are slower in developing and more easily eliminated by maintenance methods. In northern New Hampshire, some roads are built of so-called gravel which has resulted from the decomposition of granite rocks and is full of angular quartz. The roads built of this material are said to give better service so far as corrugations are concerned than those, built in the same state, of glacial gravels, or those resulting from disintegration of schistose rock. It is claimed in Wisconsin that the best service given by gravel roads, so far as corrugations are concerned, is found where pit-run gravel is passed through a crusher and only the material which ranges in size from 1″ down is used. Highway engineers, notably some in Wisconsin and in Oregon, object to any clay binder in the gravel and prefer only the fines produced by crushing and such as result from surface wear.

"During the writer's investigation in the state of Maine it was noted that roads with a relatively high per cent of clay-silt binder were comparatively free from corrugations. On one road on which rhythmic corrugations were well developed a patch near the center of the road, about 70′ long and varying from 1 to 4′ in width, was uncrossed by corrugations, and had a hard, smooth surface. Examination showed that this patch had about 5 % more clay-silt bond than the surrounding road.

"On the gravel road between Waterville and Bangor corrugations develop rapidly during the summer traffic, and are kept down only by constant maintenance for almost its entire length. Comfortable travel on this road was made possible only by continuous use of drags and planers. One short section of the road, however, was practically free from corrugations throughout the summer. This section was built of a softer gravel, which was high in clay-silt bond. Unfortunately, though, while this section of the road gives satisfaction during the summer months, it is said to be nearly impassable in the spring. Thus it may be that an all-year gravel road that will not require intensive maintenance cannot be built in states subject to heavy freezing and wet seasons.

"This problem remains for future solution and must be worked out by a combination of field observations and laboratory tests. In this connection it may be stated that the present standard tests of gravel are unsatisfactory in that they do not include determination of the nature and qualities of natural binder originally in the gravel. The so-called cementing-value test has to do only with the products of abrasion of individual gravel particles. While it is important to determine this factor, there must also be a determination, in addition to the facts brought out by mechanical analyses as to the quantity of clay-silt binder, of the cementing value of this fine material. The writer is now engaged in experiments connected with the testing of different mixtures of gravel, sand and clay-silt binders, and their behavior under different degrees of compacting and with different amounts of water present. In future investigations, observations must be made over a wide area and under varying conditions as to the relation between the amount and kind of natural binder in the road and the behavior of the road under traffic. Another interesting problem in this connection is the question of migration of clay binders toward the surface, and their ultimate loss to the road through the combination of rain, wind, and traffic influences.

"**The Effect of Dust Preventives and Surface Binders.**—A preliminary study had been made of problems of surface-treated gravel roads. Matters of methods, costs, and service have been studied to some extent in certain states. Surface binders, in a general way, prevent development of corrugations, and where these do not occur on binder-treated roads, it has been demonstrated that they result from excessive quantities of bituminous material. This statement does not refer to dust-prevention treatment, and is perhaps not true of glutrin-treated roads. Some states use both tar and oil binders, some will use only oil, and others only tar. One state, at least, uses glutrin almost exclusively. Dust preventives have been seen to fulfil

the primary requirement. Their effect on corrugations, however, is not yet clear. It is not unlikely that they delay the development of rhythmic corrugations of the first type discussed above. It is clear, however, that they do not prevent their development. They successfully lay dust for long periods, in spite of heavy traffic, and they lengthen the life of a road by retarding loss of surface material.

"**Maintenance Methods.**[1]—The maintenance required by a gravel road depends, of course, largely upon the amount of traffic to which it is subjected. If this does not exceed 200 to 300 cars per day, occasional dragging, especially after rains, will keep the surface in good condition. As traffic increases, however, surface maintenance must be practically continuous, and even then dragging or scraping will not keep a road free from corrugations. The planer, a simple machine familiar to all highway engineers, is employed in addition to the drag and road scraper. Planers[2] are of different types. Those used in some states have a single cutting blade, while those used in other states have several shorter blades so arranged as not to cut down corrugations but to distribute and rearrange the surface materials. Apparently, the best machine for eliminating corrugations has not been devised. The planer certainly does not always remove them, some of the bases of ridges being left so that traffic may, in 24 hr. after the planing of the road, reproduce the corrugations in original form and position. Even resurfacing with 1½ to 2″ of gravel, following planing of the road, will not prevent the immediate recurrence of corrugations which have not been entirely eliminated by planing and dragging. In Wisconsin, some gravel roads subject to heavy traffic are scarified once or twice during the summer months, and left to be recompacted by traffic. This is heroic treatment. Experiments are contemplated for this coming field season which may lead to improving maintenance methods, so far as corrugations are concerned. The whole subject of maintenance of gravel roads, and its costs and economic significance, will be discussed in another paper."

The following condensed report shows a case where gravel construction was recommended on a primary state road.

FEDERAL AID PROJECT 184 WOODVILLE—BRISTOL SPRINGS—CHESHIRE

"**Alternate Estimates.**—Three alternate estimates are submitted. Any of these will serve the purpose and each has certain desirable features.

"**First Estimate, Reinforced Cement Concrete 7″, 6″, and 7″ Mesh and Bar.**—This design is estimated at $620,000, or an increase of approximately $154,000 over the estimate of August, 1922. Approximately $36,000 of this increase is due to relocation changes requested by the Office of Public Roads. Approximately $118,000 of the increase is due to change in pavement thickness, guard-rail type, culvert improvements, and increase in unit prices.

"This design will satisfy the Office of Public Roads but will not satisfy the local authorities, due to large increase in cost.

"As per our previous correspondence, there is some doubt as to the advisability of attempting to construct a concrete pavement on the fresh high fills and new side-hill grading, Sta. 0–240, for a series of short breaks aggregating from 3000 to 7000 lineal feet as per list attached to alternate typical section.

"**Second Estimate, Oiled-gravel Pavement.**—This design is estimated at $450,000 as compared with the August estimate of $466,000. This design is based on a 13″ oil-gravel pavement with extra subbase for the entire length of the road. It also used guide posts as per original estimate on straight alignment.

"This design will satisfy the Office of Public Roads and the local authorities. It will increase the yearly maintenance charge for the first few years until recapped, but, considering the volume of traffic, this will not be beyond the bounds of reason, as indicated by our maintenance records for this type under light traffic. This design seems to be the most rational solution for this particular road, considering all the factors involved, namely, high cost of grading, impossible to eliminate and still get the approval of the U. S.

[1] Mr. Ladd's report bears out local experience that maintenance costs increase very rapidly where the volume of traffic exceeds 450 to 500 daily average.

[2] See p. 571, Chap. VII.

Bureau; second, limited local funds; third, economy of final cost as compared with concrete-pavement construction.

"Third Estimate, Combination of Concrete and Oiled Gravel.—This design is estimated at \$584,000, or an increase in cost of \$118,000 over the estimate of August, 1922. This design substitutes a 13″ oiled-gravel pavement for cement concrete on the doubtful grading sections of the road. It also used guide posts in place of cable rail on straight alignment.

"This design will satisfy the Office of Public Roads and may serve as a compromise solution with the local authorities, provided the Department desires to use concrete on this road.

"Pavement Type.—This road is isolated from railroad shipping points and imported materials would be prohibitive in cost. There is a limited amount of local boulder stone, 7000 to 10,000 cu. yd., widely scattered and difficult to collect, Sta. 240–519. This stone is suitable for boulder base. There is one good gravel pit of unlimited capacity on road (Long's pit, 1600′ from Sta. 140). This gravel is suitable for gravel foundations and screened gravel top course and, if washed, for cement concrete pavement. This gravel seems to be the most feasible source of supply. Alternate estimates have been prepared for cement concrete pavement 7″, 6″, 7″ costing approximately \$3.40 per square yard and for a 13″ oiled-gravel pavement costing approximately \$1.50 per square yard. There are 86,000 sq. yd. of pavement on this job.

CEMENT CONCRETE 7″, 6″, 7″ MESH AND BAR

Cost per square yard

0.18518 cu. yd. concrete at \$7.90	\$1.46
0.3518 bbl. cement at \$3.90	1.37
9 sq. ft. mesh at 5.5 cts	0.50
2.81 lb. bars at 3.6 cts	0.10
	\$3.43

86,000 × \$3.40 = \$292,400.
Average maintenance, 0.8 cts. per square yard.
Class III traffic (less than 500 vehicles daily).

GRAVEL PAVEMENT OILED 13″ DEPTH 6″, 4″, 3″

Cost per square yard

0.278 cu. yd. pit-run foundation at \$3.40	\$0.95
0.083 cu. yd. screened top at \$5.20	0.43
0.37 gal. oil at 15 cts	0.06
3 lb. calcium chloride at 1.2 cts	0.04
	\$1.48

86,000 × \$1.50 = \$129,000.
Average maintenance, 6.5 cts.
Class III traffic (less than 500 vehicles daily). Under these conditions the gravel pavement seems to be a desirable solution.

W. G. Harger,
Designing Engineer.

MISCELLANEOUS SPECIAL CASES

Alaskan Trails and Roads.—Alaskan climatic and soil requirements afford special problems; the following quotation from *Engineering and Contracting* of Mar. 6, 1918, indicates an interesting condition as described in the report of the Alaskan Highway Commission:

"The most unusual and troublesome feature encountered in construction is the permanently frozen ground which covers a large portion of the entire interior, and which is protected from thawing during the summer by a thick layer of moss, turf, or decayed vegetable matter. The character of this frozen material varies largely

in different sections of the territory, and even in the same section. It may be gravel, clay, silt, peat, or clear ice, or a combination of two or more of these elements.

"When gravel is encountered the problem presents no special difficulties; the moss or turf is stripped off, and the road graded in the usual manner. When the material is clay, experience has shown that the same procedure can usually be followed, but the grading is a slow and rather expensive process. After the protective covering of vegetable matter is removed, it is necessary to allow the soil to thaw and dry out somewhat before it can be worked, and unless a considerable period is allowed to elapse between the stripping and the grading, it will be found that the thawing is not extended to sufficient depth to permit of completing the grading in one operation. When the necessity for the road is not pressing, an appreciable saving can be effected by stripping the roadbed and digging drainage ditches during one season, completing the construction the next year.

"In those localities, however, where the frozen material is silt or peat the stripping of the roadbed quickly results in the formation of a quagmire through which a man or horse, even without a load, can pass only with the greatest difficulty. Such soil has sufficient bearing value only as long as it remains frozen, which makes it desirable that the moss or turf overlying it be kept intact. This layer of vegetable matter is not of itself able to sustain traffic, necessitating the addition of a protective covering—usually of scrub spruce timber which covers a large part of interior Alaska, except the Seward Peninsula, and affords excellent material for this corduroy.

"Where the trees are large enough, pole corduroy is constructed by grubbing all stumps and roots from the roadbed, leveling it and laying perpendicularly to the axis of the road a single layer of poles from which the largest and stiffest branches have been trimmed. Ditches are then dug at a distance of 3 to 5′ from the ends of the poles, and the material therefrom, after rejecting the top layer of vegetable matter, is placed on the corduroy for the double purpose of protecting it from wear and affording a smoother roadway. If the soil in the ditches is entirely unsuitable for this covering, other material, preferably gravel, is hauled on from the nearest available source.

"Where the spruce timber is of very small size, or where only small willows are available, as on the Seward Peninsula, brush corduroy is used. The method of construction is similar to that described above, except that the single layer of poles is replaced by a mattress of untrimmed brush containing sufficient material to give a thickness of at least 6″ when compressed.

"When corduroy has been properly protected, its life in most parts of Alaska is quite long. Poles taken out of the road after 10 years of service have been found to be in excellent condition.

"The 3′ to 5′ berm which is left between the ends of the corduroy and the ditches is very necessary to protect the corduroy from undermining, as the ditches, under the action of sun and rain, slough and cut rapidly. Ordinarily, as the frozen soil thaws and cuts away

the moss, the berm gradually assumes a gentle slope to the bottom of the ditch, effectually protecting the corduroy, but where the cutting is severe, it often becomes necessary to revet the insides of the ditches with moss or turf. Frequent outlets from the ditches must be provided, and when the amount of water reaching the ditch on the upper side of the road is large it is advisable to construct an additional ditch parallel to the road and about 50′ away, with sufficient outlets to culverts of ample size.

"Along the Pacific coast of Alaska no frozen ground is encountered, but the mountainous character of the country, the excessive rainfall, and the difficulties of clearing have made the work, as a rule, even more expensive than in the interior. Unless the soil encountered in this region is gravel, it will not stand up under traffic during the heavy and continuous rains, and some protective covering is required. Fortunately, gravel is usually found at no great distance; otherwise plank or corduroy roads are constructed.

"The numerous swift streams of glacial origin found in the Pacific coast section and throughout the Alaskan range in the interior have been the source of much trouble and expense. Flowing through gravel beds varying in width with the volume of water carried up to 2 miles or more, they rarely have any fixed channels. It is by no means uncommon for one of these streams to abandon an old channel and establish itself a new one ½ mile away almost overnight. When warm weather causes rapid melting of snow and ice in the glaciers, these streams become raging torrents of enormous destructive force, and roads paralleling them are in constant danger of being washed away. Numerous methods of bank protection to prevent damage from this cause have been tried, of which the following has proved to be the cheapest and most effective. A layer of loose brush of sufficient length to give the requisite protection is placed on the threatened bank, perpendicular to the current and weighted below the center with stone enveloped in galvanized-wire netting, the whole being anchored in place by wires extending to 'dead-men.' For emergency work when the water is too high to permit of placing the wire netting and rock, the brush is made into fascines enclosing sacks of earth, which are then placed against the threatened bank and wired to it and to each other. This form of protection is easily and quickly constructed and has repeatedly demonstrated its effectiveness.

"As now constructed, the width of wagon roads varies with the formation of the ground and the amount of traffic expected, but, as a general rule, roads graded by other means than the road grader are given a minimum width of 20′ between ditches, and those on which the grader is used a minimum width of 24′. On steep side hills and where rock work is involved, the width is reduced to 10 or 12′. The standard width of clearing is 30′, but this is increased to 60′ where necessary in order to secure the beneficial action of wind and sun on the roadbed.

"Sled roads for winter traffic are cleared for a width of 16′, with all stumps, hummocks, and similar obstacles removed for a width of 8′. They are constructed where the amount of traffic is not large enough to justify a wagon road, where the cost of building a

wagon road would be prohibitive, or where the communities along the route are amply served by water transportation during the open season, as is the case with the Fairbanks-Fort Gibson sled road. If it seems probable that future development may demand or justify a wagon road, the location is made for wagon road, in order that work done on the sled road may be of use when the improvement is made.

"Trails designated for travel by dog team in winter or by pack train in summer are given a width of 8′ with all stumps and underbrush cut off as close to the ground as possible.

"In the past, the work of constructing and gradually improving the roads has been so generally intermingled with maintenance operations that a systematic plan for maintenance has not been put

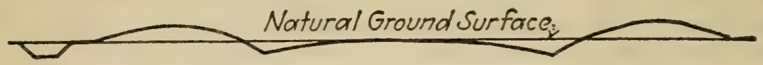


FIG. 118.—Roadbed below natural ground elevation.

into effect, nor would such a plan have been feasible in view of the uncompleted state of the roads. At the present time, however, the condition of parts of the more important roads, notably the Valdez-Fairbanks road, is such as to make practicable their maintenance by dragging. As Alaska has only a very small agricultural population, the method adopted in many states of contracting with farmers adjacent to the road for the necessary dragging cannot be used, but

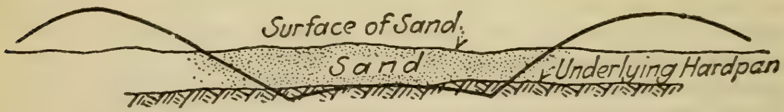


FIG. 119.—Roadbed on underlying hard formation.

it is intended to place on completed sections small maintenance crews consisting, as a rule, of two men each, supplied with a team, wagon, drag, and the necessary small tools. Two such crews have been employed on the Valdez-Fairbanks road during the present summer, with very satisfactory results. On several of the gravel-surfaced roads in southeastern Alaska the patrol system of maintenance has been used in connection with more extensive repairs. The results show the method to be very effective for roads of this character.

"The average costs per mile, including construction and maintenance of all roads and trails constructed by the board since its organization in 1905, are as follows: wagon road, \$3419; sled road, \$379; trail, \$113. A division of these amounts to show the exact cost of construction proper is impossible, but a careful analysis of the available data indicates that the following unit costs of construction, including bridges may be accepted as approximately correct: wagon roads, \$2475 per mile; sled roads, \$300 per mile; trails, \$65 per mile. The average costs of maintenance during the

past season were as follows: wagon roads, \$250 per mile; sled roads, \$41 per mile; trails, \$8 per mile."

Arid Regions.—In the arid regions, fills must be avoided. Ordinary earth roads are constructed below the general elevation of the ground which keeps them moist longer (see Figs. 118 and 119); shallow ditches are used for the same reason. In many cases a hardpan formation underlies the sand surface and in these conditions the sand surface is scraped off and the road built on the underlying strata.

Where fills must be used they should be made during the rainy season and the addition of clay to a sandy soil helps consolidate the traveled way. Readers are referred to the reports of the state engineers of New Mexico and Arizona for further data on the special treatment of roads under these conditions.

CHAPTER VI

MACADAM AND RIGID PAVEMENTS

Introduction.—The types of pavement discussed in this chapter cover the forms of construction generally used for main state-aid or country-aid highways ranging in traffic volume from 200 to 20,000 daily. Chapter I outlined economic selection of type, Chapter III, data on widths, crowns, etc. The design of strength and the economic selection of various types of foundation courses are described in this chapter as a preliminary to the discussion of pavement details.

DESIGN OF PAVEMENT STRENGTH

Fundamentals of Pavement Design.—Before discussing in detail the various factors in design, it is, perhaps, just as well to outline the fundamental differences between flexible-pavement and rigid-pavement design; it will be noted that each type has certain well-defined advantages.

Utilization of Subgrade Support.—Macadam or flexible-base pavements move in conjunction with and stay in contact with the underlying earth subgrade. If unequal settlement of the subgrade occurs, the surface becomes uneven under traffic action but continues to transmit the wheel loads directly to the underlying subgrade. These surface inequalities can be easily and cheaply repaired without destroying the effectiveness of the underlying pavement. If large areas settle, the pavement follows the movement without any particular loss of effectiveness. *Macadam design is based on the principle of utilizing subgrade support at all points. The pavement thickness is varied to produce the maximum allowable pressure on the subgrade and in this way utilize the full supporting value of the subgrade.*

Rigid pavements do not conform to the settlement of the subgrade. They bridge over small areas where the underlying soil has settled and they fail entirely where large areas settle unevenly. *Rigid-pavement design is predicated on the lack of soil support for small areas. The pavements are designed to bridge over small areas by means of their slab or beam action (as this is the main advantage of the type), but the cost of applying this method of design for large areas of settlement is prohibitive. Rigid-pavement design cannot utilize soil support to its full value;* that is, a rigid pavement strong enough to bridge over small areas of no support has a needlessly high distributing power (even on poor soils) where the pavement is in actual contact with the subgrade.

The frequency or size of the small areas of no support seem to have very little relation to the relative normal supporting power of different subgrade soils within the usual range of foundation soils. These small areas of no support are due more to non-uniformity of the subgrade, to warping of the slabs due to temperature, and to construction imperfections rather than to low general supporting power of the soil. Some increase in rigid-pavement strength is desirable on clay as compared with sand support, but it certainly is not inversely proportional to the supporting power of the subgrade soils.

The practical effect of this fundamental difference is shown by the wide range in depth required for macadam roads on different soils as compared with the small required range in strength of rigid pavements laid on these same varying soils.

From the standpoint of comparative construction costs, macadam generally has a distinct advantage over rigid pavements where the subgrade supporting power is high, as relatively thin macadam construction is then permitted. It loses this advantage as the soils become poorer in supporting power, necessitating a large increase in macadam depth as against a small increase in rigid-pavement strength. When a really unstable soil where settlement occurs over large areas is reached, however, a rigid pavement is not feasible without the use of underlying macadam base and the macadam type regains its advantage.

Table 63.—Tabulation Showing Approximate Effect of Foundation Soils on the Relative Construction Costs of Typical Bituminous-macadam and Cement-concrete Pavements under Class II Traffic

Foundation soil	Approximate construction cost per square yard (1922)	
	Bituminous macadam	Cement concrete
Coarse sand and gravel	$2.00	$2.80
Loams	2.30	2.90
Clays (ordinary)	$2.60–$3.40	$3.00–$3.20
Wet clay and quicksand	3.00– 3.80	3.60– 4.00

Effect of Temperature and Frost.—*Changes in temperature, except freezing, have no effect on macadam-pavement design.*

Changes in temperature must be considered in rigid-pavement design, as they produce internal stresses, resulting in contraction cracks and "blow-ups," and produce warping, which results in lack of uniform soil support for the slabs.

Frost heave very materially reduces the distributing power of macadam pavements for a short time in the spring by breaking the tight internal lock, and it is at this time that most macadam failures occur, as the subgrade is at its worst at the same time that the pavement has the least distributing power; *that is, in order to prevent*

failures entirely for a short time in the spring, macadam must be designed needlessly thick, considering its distributing power for the balance of the year. It is prohibitive in cost to design for this extreme combination of unfavorable conditions under heavy traffic on poor soils, and in practice reasonably safe depth is provided, with the idea of minor repair and some restriction on heavy loads for a short time in the spring.

Temperature changes do not affect the internal resisting moment of rigid pavements, which is constant the year round, but temperature changes produce slab distortion, cracks, etc., which increase the normal stress in the pavement. The effect of temperature must always be considered in rigid-pavement design.

Effect of Traffic Loads.—Occasional extremely heavy loads far above the normal vehicle load are not disastrous to the macadam type, as this type of road is more or less self-healing and knits together again under rolling or well-distributed normal load traffic; that is, *macadam roads can be safely designed for the normal maximum vehicle load.*

If a rigid-pavement slab is cracked by exceptionally heavy loads, this crack is not self-healing and it is very difficult to replace a portion of a slab and get reasonable bond with the adjacent pavement; that is, *rigid-pavement design must consider the exceptional load.*

This general fact tends to warrant a difference in design loading for the two types of pavement.

Effect of the Critical Location of Loads.—Critical loading will be discussed in detail later. At this point the discussion will be anticipated by stating general conclusions in order to complete the

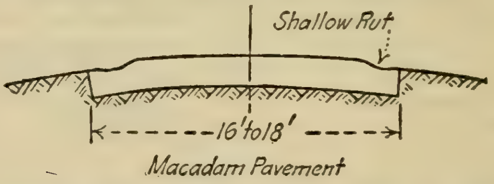


FIG. 120.—Typical shallow ruts along edge of Class I traffic macadam pavement.

comparison of the differences in design fundamentals. On macadam pavements the wheel loads which cause the worst distribution of pressure to the subgrade are located along the edge of the macadam. At this point part of the distributing value of the macadam is lost. This fact does not have much effect where the shoulder is a well-consolidated gravelly soil, but for shifting sand or wet clays it helps cause the formation of a shallow rut along the edge on heavy-traffic roads carrying a continuous double line of traffic (see Fig. 120). This situation, however, applies only to Class I traffic roads and need not be considered in the design of roads, of Classes II, III, and IV, as on these roads there are few cases where heavily loaded wheels follow close to the edge continuously enough to cause trouble.

There is not much probability of adjacent wheel loads of passing rigs being close enough together to cause critical loads continuously in the central part of the road. *Flexible-base pavements on Class I roads must consider the critical location of load. Macadam pavements on roads of Classes II, III, and IV are designed for the normal wheel-load location.*

On rigid pavements the critical location of wheel loads is at the corners of slabs. Such corners occur both at the pavement edge or at internal points due to longitudinal joints or temperature cracks (see Fig. 136, p. 405). Wheel loads at critical points occur quite continuously at internal corners and with moderate frequency at outside corners on heavy-traffic roads. *Rigid-pavement design is predicated on utilizing critical-load location in designing strength.*

Effect of Future Resurfacings on Strength Factor of Safety.—The strength of a macadam road can be increased at any time by the construction of a new top course on the old road. The distributing power of macadam varies about as the square of the depth, and it makes no difference whether the different layers are constructed at the same time or at intervals. This means that if at any time the loading on a macadam road increases or if the original construction proves too weak for increasing traffic the pavement can be strengthened without much loss in total final cost. This warrants using a low factor of safety in original strength design.

While the resurfacing of rigid slabs adds something to their strength, the construction of successive layers is not an effective way to increase beam or slab strength. Rigid slabs must be originally constructed at least amply strong for existing traffic and some provision may well be made for heavier future traffic; that is, the factor of safety should be somewhat higher than for macadam design.

Effect of Construction Imperfections.—The strength of pavements depends largely on the excellence of construction, and in designing some allowance must be made for common imperfections.

Macadam is less damaged by careless manipulation than rigid pavements. The settlement of new fills causes more cracking of rigid pavements than any other factor.

TABLE 64.—SUMMARY OF FUNDAMENTAL FACTORS IN DESIGN

Macadam Types	*Rigid Types*
1. Soil support is utilized at all points.	1. Soil support cannot be utilized at all points.
2. Full soil support can be utilized.	2. Full soil support cannot be utilized.
3. The soil support used must be lowest value, considering seasonal variation.	3. Seasonal variation of soil supporting power has only a minor effect.
4. Macadam strength varies at different times.	4. Rigid slab strength is constant.
5. Occasional excessive loads need not be considered.	5. Occasional excessive loads must be considered.

TABLE 64.—(*Continued*).

Macadam Types	*Rigid Types*
6. The special location of loads need be considered in only a few cases.	6. The special location of loads must always be considered.
7. Temperature stresses need not be considered.	7. Temperature stresses must be considered.
8. A comparatively low factor of safety is warranted.	8. A fairly liberal factor of safety is necessary.
	9. Rigid pavements composed of separate concrete base and resilient surface coursees reduce impact damage and warping due to daily temperature fluctuations and increase wheel-load distribution over base cracks.

If the design of either macadam or rigid pavements provided for the most extreme combination of unfavorable conditions for every factor involved, the pavement would be prohibitive in cost. It is apparently sound policy to provide for probable combinations of unfavorable conditions and plan on minor repair for a small percentage of failure. Reasonable design hinges on the assignment of proper values for the various factors of wheel load, supporting power of soils, distributing power of macadam pavements, and slab strength for rigid pavements.

Traffic Loads.—The maximum loading on pavements is produced by the modern commercial truck traveling at high speed. Horse-drawn farm vehicles and the ordinary passenger automobile can be disregarded as far as the load factor is concerned. Even military field ordinance loads are no more severe than the commercial truck loading.

Statutory limitations on load, speed, and various other factors are necessary to insure against the needless destruction of pavements. Existing statutes limit vehicle gross load, axle load, wheel load, load per lineal inch of tire width, and speed. Such statutes may well be broadened to include limitation of the use of heavy trucks to roads of Classes I and II and also various factors in truck operation which increase impact, such as badly worn tires, spring equipment, etc. While local statutes vary, the essential features have been standardized by common agreement to approximately the following values (1923 for commercial highways):

Maximum gross weight, 22,000 to 28,000 lb.
Maximum wheel load, 8000 to 10,000 lb. (weight at rest).
Maximum load per inch width of tire, 600 to 800 lb.

TABLE 65.—LIMITATIONS OF TRUCK LOADS ON HIGHWAYS (1923)

State	Maximum Gross Weight in Pounds (Four Wheels)
Alabama	20,000
California	30,000
Colorado	16,000
Connecticut	25,000
Delaware	22,000
Florida	16,000
Indiana	24,000
Illinois	32,000
Iowa	20,000
Maine	20,000
Maryland	20,000
Minnesota	28,000
Nevada	25,000
New Hampshire	20,000
New Mexico	12,000
New York	28,000
North Carolina	15,000
Ohio	20,000
Oregon	22,000
Pennsylvania	26,000
South Dakota	20,000
Tennessee	20,000
Texas	22,000
Utah	20,000
Vermont	12,500
Virginia	20,000
Washington	24,000
Wyoming	25,000

The Pennsylvania (1921) law is representative of the usual solid-tire truck-speed regulations.

TABLE 66

Class	Gross load, pounds	Speed, miles per hour
AA	7,000	20
A	11,000	20
B	15,000	18
C	20,000	15
D	24,000	15
E	26,000	12
F	26,000	10

These legal load limitations do not represent design loads, as impact increases the static load of a truck at rest. For well-main-

tained, moderately smooth pavements, however, the effect of impact does not probably add over 25% to the static wheel load at rest for the larger trucks traveling at legal speeds (see Table 67, U.S. Bureau of Public Roads Impact Tests). For the smaller solid-tire trucks at higher speeds it may add 100%. For pneumatic-tire trucks it does not probably exceed 10% on the average. The tests recorded some cases of 400 to 500% increase due to impact, but these represented conditions of roughness that would not occur

TABLE 67.—IMPACT CAUSED BY DIFFERENT MOTOR TRUCKS
(*U. S. Bureau of Public Roads*)

Rated capacity of truck, tons	Load, tons	Load on one rear wheel			Equivalent static load for different heights of fall		
		Total	Sprung	Un-sprung	0	¼″[a]	1″
1½	1½	3,475	2,410	1,065	5,500	7,800	10,200
1½	1½	3,475	2,410	1,065	4,500	6,300	11,500
1½	2¼	4,240	3,175	1,065	4,700	10,000	16,000
1½	2¼	4,240	3,175	1,065	4,900	5,900	9,200
2	2	4,300	3,300	1,000	6,800	7,800	11,500
2	2	4,300	3,300	1,000	6,800	8,500	13,400
2	2	4,300	3,300	1,000	6,800	7,900	11,000
2	2	4,300	3,300	1,000	6,800	7,500	11,000
2	3	4,900	3,900	1,000	7,200	8,500	14,000
2	3	4,900	3,900	1,000	7,300	8,600	13,700
2	3	4,900	3,900	1,000	6,800	8,000	11,000
3–3½	2½	5,150	3,450	1,700	8,400	9,200	15,700
3–3½	2½	5,150	3,450	1,700	8,200	8,700	11,800
3–3½	2½	5,150	3,450	1,700	8,200	9,300	14,100
3–3½	2½	5,150	3,450	1,700	6,900	9,200	21,500
3–3½	2½	5,150	3,450	1,700	8,000	8,200	12,200
3–3½	2½	5,150	3,450	1,700	8,700	8,200	13,000
3–3½	4½	7,000	5,300	1,700	......	10,000	19,000
3–3½	4½	7,000	5,300	1,700	9,700	9,700	19,000
3–3½	4½	7,000	5,300	1,700	9,300	9,800	17,700
3–3½	4½	7,000	5,300	1,700	9,200	11,000	17,200
3–3½	4½	7,000	5,300	1,700	10,000	10,000	18,000
3–3½	4½	7,000	5,300	1,700	10,000	11,000	15,800
5	5	7,900	5,950	1,950	11,000	12,800	18,000
5	5	7,900	5,950	1,950	11,000	12,500	19,000
5	5	7,900	5,950	1,950	9,000	10,000	16,000
5	5	7,900	5,950	1,950	9,200	10,700	15,500
5	5	7,900	5,950	1,950	9,200	9,700	13,000
5	5	7,900	5,950	1,950	9,500	......	15,000
5	7½	10,600	8,650	1,950	12,200	15,300	26,000
5	7½	10,600	8,650	1,950	12,000	13,700	21,000
5	7½	10,600	8,650	1,950	11,500	12,500	18,500
5	7½	10,600	8,650	1,950	11,500	12,600	17,200
5	7½	10,600	8,650	1,950	11,000	11.200	16,800
5	7½	10,600	8,650	1,950	11,200	12,100	15,800

[a] The ¼″ column is assumed to represent probable impact on well-maintained roads.

on well-kept pavements. The extreme loads resulting from impact on rough surfaces emphasize the necessity for the construction of reasonably smooth pavements properly maintained. *It would be impracticable to design pavements on the basis of high-impact stresses.* Attention should be concentrated on the reduction of impact to the minimum feasible amount, which is assumed to be represented by the ¼″ column of Table 67 for the smoother pavements, such as modern macadams, sheet asphalt, grouted brick, and concrete, and a somewhat higher value for the rougher types, such as stone block, brick with bituminous filler, etc. Vialog records (discussed on p. 545) indicate that the ¼″ impact is a reasonable basis of design.

The tractive effort of mechanically propelled vehicles is a surface shearing force and can be disregarded in deriving design loads for pavement-strength formulas. It has some effect in producing humps and hollows in asphaltic-concrete and bituminous-macadam surfaces and probably hastens disintegration of bond between poorly bound block surfaces and is a contributary cause of vibratory disintegration of rigid monolithic pavements.

Recommended Design Loads.—It seems rational to recognize at least two load classifications due to general character of traffic and also variations due to pavement surfaces.

Main Roads of Classes I and II.—These roads should be designed for the heaviest commercial trucks permitted by law. It is probable that a design wheel load of 14,000 lb. (11,000 lb. static plus 3000 lb. impact) distributed over a 12″ tire width represents about the maximum load produced by present-day heavy traffic operating at legal speeds on well-maintained rigid pavements, such as cement concrete, monolothic, or semimonolithic brick with cement-grout joints on concrete base, etc. Pavements having a surface or base which has some flexibility and resiliency are undoubtedly less damaged by impact than the more rigid types. How much weight can be given to this in design is not known, but in order to recognize this factor it is well to adopt a slightly lower value than shown in Table 67. Twelve thousand pounds on a 12″ tire will be assumed for bituminous macadams, small blocks with asphaltic joints on macadam bases, and asphaltic-concrete surfaces on either macadam or concrete bases. For the rougher pavements, such as stone block or brick with bituminous joints on concrete bases, a value of 15,000 to 16,000 lb. is probably not excessive.

Local Roads of Classes III and IV (Macadam Design).—For these roads a lower design load is logical. A total of 9000 lb. (5000 lb. static plus 4000 lb. impact) on a 10″ tire is liberal and a design allowance of 7000 lb. on a 10″ tire width is probably about the desirable maximum limit for purely local roads carrying less than 300 vehicles daily. Roads of classes III and IV are at times subjected to heavy-truck Class I loading under existing traffic-regulation statutes, but it is probably sound policy to use the lighter design loading and make an effort to modify existing regulation to the extent of keeping the heavy trucks off from these local roads, particularly in the spring. While it is probably impossible to prevent heavy trucks from violating such statutes entirely, an

occasional violation is not serious, as is noted under General Basis for Design of Macadam Roads (p. 368). The recommended loading permits all-year-round use of the ordinary 2½-ton agricultural trucks and gives sufficient strength in the summer season to permit the use of these roads as temporary detours for heavy traffic at times when the main roads are closed on account of construction or repair.

TABLE 68.—RECOMMENDED DESIGN LOADS

Class of road	Design static wheel load (including impact)
I and II.......	16,000 lb. on 12″ tire, rougher types rigid pavements 14,000 lb. on 12″ tire, smooth, rigid pavements 12,000 lb. on 12″ tire, resilient pavements
III............	12,000 lb. on 12″ tire, rigid pavements 9,000 lb. on 10″ tire width, macadam pavements
IV	7,000 lb. on 10″ tire width, macadam pavements

These concentrated wheel loads must be transmitted by the pavement and applied to the underlying earth subgrade over a large enough area to prevent rapid unequal settlement or permanent displacement.

Supporting Power of Soils.—Different soils have a wide range in supporting power, and even the same soil varies greatly at different times, due to moisture content, freezing action, and degree of consolidation. Road foundation soils fluctuate more in their supporting power than deep foundation soils for buildings, as they are near the surface and are subject to the effects of rain, frost, and the churning action of rapidly fluctuating loads.

Pavement design, to be rational and fairly consistent, must consider variations in the supporting power of the underlying subgrade, but it can only consider such differences in soil conditions as are clearly defined. It is impracticable to give much attention to minor variations; that is, for a specific road, the supporting power of soil varies foot by foot, and even for the same point it changes at different times in the year. For these reasons, any attempt to apply laboratory methods to rapidly fluctuating subgrade conditions is impracticable, to say the least. It is feasible to provide changes for well-defined differences in soil conditions which become evident to an experienced highway engineer during the progress of the survey and construction. It is practicable to eliminate excessive ground-water seepage by the use of underdrains and to reduce surface-water seepage by well-constructed and well-maintained shoulders and ditches and by the constant sealing of cracks in rigid pavements. Even with these precautions, water will work in from the shoulders or reach the subgrade through cracks in the pavement and in this way temporarily reduce the supporting power of the earth subgrade. All pavement and foundation design must be predicated on the fact that the supporting power of the underlying earth will vary at different times, and the important factor in design is minimum supporting power, considering all-year-round conditions for local climatic conditions.

Experience has demonstrated that coarse sands and gravel do not vary much in the supporting power at different seasons if protected by well-designed drainage. It is known that loams, clays, and fine sands vary considerably in supporting power where they are located in cuts or thin "pancake" fills even when protected by well-designed drainage, and that these same soils in fills over 3′ deep do not vary much at different seasons, provided the pavement surface is reasonably waterproof and the shoulders are maintained to shed water rapidly. Figure 121 shows in a general way the effect of moisture content on the supporting power of different soils. Experi-

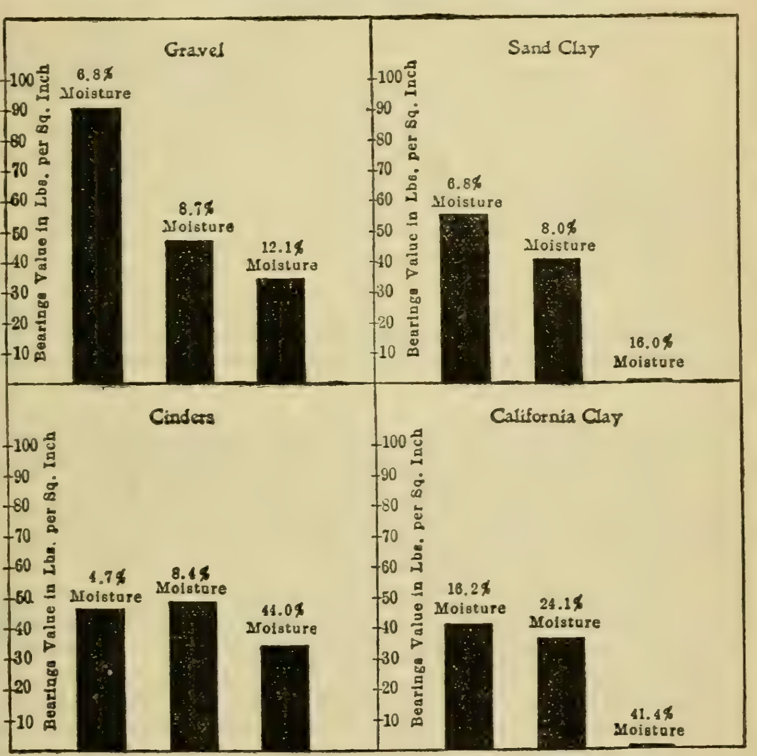


FIG. 121.—Effect of moisture content on bearing power of soils. U. S. Bureau of Roads testing records.

ence has demonstrated that under normal road conditions it is fairly easy to prevent a large variation in the moisture content of coarse sand and gravels and increasingly difficult to control the moisture contents of loams, clays, and quicksands. The vertical rise of moisture due to capillary action is shown in Table 69. Moisture content for roadbeds in cuts is reduced by open ditches and underdrains, but these methods fail in effectiveness at times due to all sorts of reasons, such as frozen drains and shoulders, and poorly maintained shoulders, permitting pools of water to stand and seep

in cracks in rigid pavements. Where the road is in cuts or on thin fills they are certain to get at times a higher moisture content than where the roadbed is on a high fill which is free from groundwater seepage and above the limits of vertical capillary lifting action. *As macadam design utilizes full support, it must not only recognize the difference in soils but it must also recognize whether the soil is in cuts or fills.*[1]

Table 69.—Table of Heights to Which Capillary Water Rises in Different Soils (*Experiments by U.S. Bureau of Public Roads*)

Soil	Height in 24 hr., inches	Approximate final height, inches
Light sandy soil	14	28
Gravelly soil	16	32
Decomposed granite (loam)	21	40
Heavy granite loam	16	32
Clay loam	12	24
Pure coarse sand	9	18

Note.—The percentage of moisture due to capillarity decreases rapidly with the height above the free water for the coarse sandy soils, while it remains nearly constant for the entire range of vertical capillarity in some of the heavier soils.

There seems to be fair agreement between widely different sources as to the minimum safe supporting power of well-compacted subgrade soils protected by well-designed drainage provisions. The Massachusetts Commission in 1901 determined these values at 25 lb. per square inch for coarse sand and gravel and at 4 lb. per square inch for the poorer clays and excessively fine sands. French experiments, quoted in Agg's "Construction of Roads and Pavements," place the values at 30 lb. per square inch for firm soils and at 9 lb. per square inch or less for the poor soils. These values are for well-compacted soils and refer to well-rolled subgrade soils kept free from an excessive moisture content by a well-designed drainage system. The necessity for thorough rolling of the subgrade is well recognized. Table 70 compares these values with the usual value assigned to these soils for deep building foundations and illustrates the radically different supporting value of surface and subsurface soils.

[1] The fact that fills reduce required depth of macadam pavements does not affect grade-line design, as the reduction in cost of macadam rarely balances the increase in grading cost due to arbitrarily raising the road by fill; that is, the consideration of pavement depth and strength never raises the road onto fills except across low, wet, swampy areas. Needless fills add danger to road traffic, always increase damage to abutting properties, and are to be avoided as much as possible, as they give no adequate return. Where fills are necessary, their construction should be taken advantage of to reduce macadam depths but not rigid-pavement depth. Most rigid-pavement troubles occur on fills due to incomplete compaction before the pavement is constructed.

TABLE 70.—COMPARISON OF SAFE SUPPORTING VALUE OF SURFACE AND SUBSURFACE SOILS, IN POUNDS PER SQUARE INCH

Soil	Road sub-grade surface soils	Subsurface building foundations
Coarse sand and gravel	25–30	60
Poor damp clay and fine shifty sand (30% or more passing 100 sieve)	4–8	15

The values of intermediate soils and the effect of fills are largely matters of judgment and experience. The following recommended values are based on the observed action of roads in western New York during the past 15 years. These values are to be used in conjunction with Formula 1 (p. 382), and are safe values for localities subject to severe winters. They can undoubtedly be increased for locations free from frost; no special values are given for such conditions, as the author's personal experience does not warrant assigning values except in climates similar to the north-eastern Atlantic states. In the course of time, values for various localities will become more or less standardized. With this in view, it is desirable for the various highway departments to make a systematic effort to record failures and successes, as shown in chart form (Fig. 131, p. 388). One of the difficulties to overcome in public highway work is the effect of rapidly changing personnel. If data are not systematically recorded, the value of experience is lost and the new men have to start in all over again to gather data. Up to date, this has been one of the main difficulties.

It can be readily seen that the classification of the soils is largely a matter of judgment, but it is entirely feasible to educate a begin-

TABLE 71.—RECOMMENDED SAFE SUPPORTING POWER OF SUB-GRADE SOILS, IN POUNDS PER SQUARE INCH, FOR LOCALITIES SUBJECT TO SEVERE WINTERS

(For use in connection with Formula 1, p. 382.)

Soil	Location		
	In cuts or on fills less than 1′ deep, pounds per square inch	Intermediate fills, 1 to 3′ deep, pounds per square inch	High fills, over 3′ deep, pounds per square inch
Fine sand (more than 30% passing 100 sieve)	4– 8	8–15	15
Heavy clay	4– 8	10–17	17
Ordinary clay	8–13	13–19	19
Clay loam	13–17	17–20	20
Loam	17–21	19–21	21
Sandy loam	21–25	23–25	25
Coarse sand	25–30	27–30	30
Fine gravel	25–30	27–30	30

ner very rapidly to distinguish between the general classifications noted in Table 71. Any attempt to classify subgrade soils during construction by laboratory methods is too costly and complicated a process to have much practical value. If the design of macadam is based on the general classifications given, the chances are all in favor of reasonably good results, particularly if the grading operations are controlled and the fills under the pavement made fairly uniform and of the best available material.

STRENGTH DESIGN, FLEXIBLE-BASE PAVEMENTS

Theoretical Design of Macadam Road Thickness.—The determination of thickness depends on the wheel loads, the supporting power of the underlying soil, and the distributing action of the macadam pavement. Wheel loads and the supporting power of soils have been determined within reasonable limits of accuracy. These determinations are based both on experiment and on the observed action of macadam pavements under actual traffic, which indicates quite strongly that they are essentially correct. It remains to discuss the distributing power of macadam pavements and to assemble the factors with a reasonable factor of safety.

Distributing Action of Macadam, Gravel, and Boulder Bases.—Experimental data in regard to the load distribution through flexible-type bases are meager. Table 72 taken from Agg's "Construction of Roads and Pavements," records certain French data which are probably as reliable as any investigations which have been made up to this time (1922). Figures 122 and 123 (p. 379) show recent tests made by the U.S. Bureau of Public Roads at Washington.

Table 72.—Showing Transmission of Pressure through Macadam

(The test was made with a wheel load of 4 tons with a $5\frac{1}{2}''$ tire)

On macadam alone:					
Thickness of crust, inches	1.97	3.94	5.91	7.87	11.81
Pressure on subsoil, pounds per square inch	102.50	47.70	27.40	17.40	9.10
On Telford foudation alone:					
Foundation thickness, inches	......	.....	5.91	7.81	11.81
Pressure on subsoil, pounds per square inch	......	.....	56.00	37.40	20.70
On combined foundation and macadam:					
With foundation thickness of, inches	......	5.91	7.87	9.84	11.81
3.94″ of top stone, pressure on subsoil, pounds per square inch	......	19.30	14.70	12.60	10.20
5.91″ of top stone, pressure on subsoil, pounds per square inch	......	13.20	10.90	9.10	7.70
7.87″ of top stone, pressure on subsoil, pounds per square inch	......	9.70	8.20	6.80	6.10

Note.—The pressure on the subsoil through a 12″ bed of simple macadam is apparently the same as the pressure through a 6″ bed of macadam laid over a 10″ stone foundation. The pressure transmitted by well-constructed gravel will be about the same as with macadam of equal thickness.

A good soil well drained will safely withstand a pressure of 30 lb. per square inch. It is considered that poor soil requires at least a 12″ macadam layer or its equivalent.

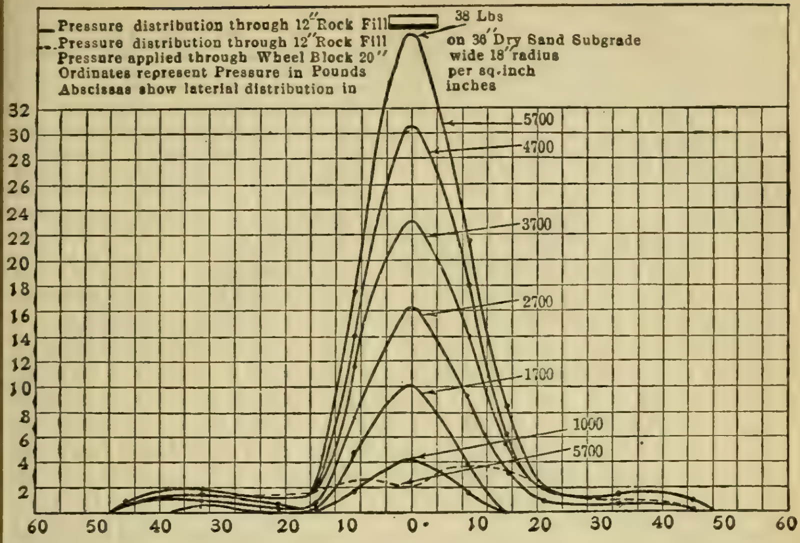


FIG. 122.—Distribution of pressure through macadam laid on sandy soil. U. S. Bureau of Roads experiment.

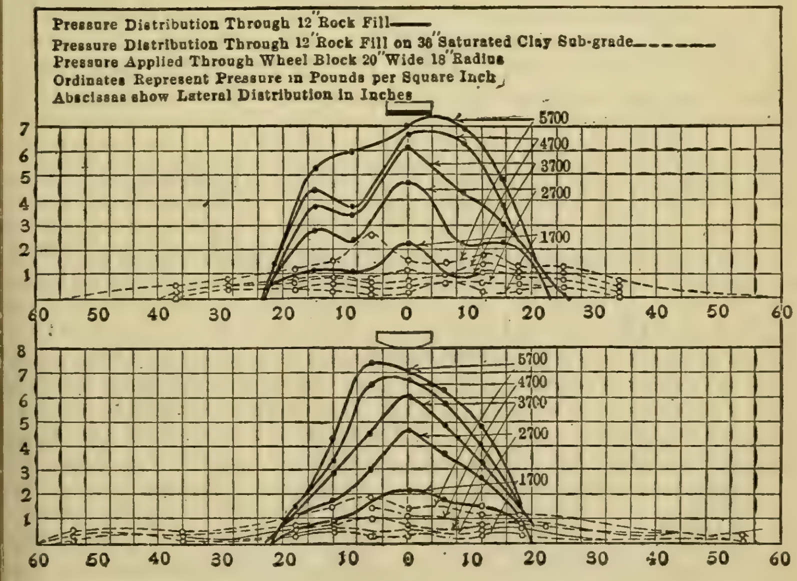


FIG. 123.—Distribution of pressure through macadam pavement clay sub-soil. U. S. Bureau of Roads experiment.

The distributing action of broken-stone macadam is slightly better than Telford or boulder base. The distributing action of well-constructed gravel courses is usually as good if not better than boulder base, although not quite so effective as macadam. The distributing power of all these types depends on the excellence of construction (degree of tight interlock and compaction), and for each type it will vary at different times of the year, the least value occurring in the spring when the tight internal lock is reduced by frost heave. In order to provide the proper thickness of macadam it is necessary to determine the effect of depth on total area of subgrade over which the wheel load is distributed and the ratio of maximum intensity of pressure directly under the wheel to average intensity over the total area of subgrade receiving pressure.

Figures 122 and 123 show that for a given depth of macadam and a certain specified load the maximum intensity of pressure directly under the wheel is greater for firm soils, such as dry sand, than it is for soft subgrades, such as wet clay; that the ratio of maximum pressure to average pressure is greater on firm soils; and that the total area of load distribution is slightly less on firm soils than on soft subgrades. This merely means that firm soils offer greater unit resistance and that, for the condition of a certain specified depth of macadam and a specified load, the deflection of the macadam under the wheel is less on the firm subgrade than on the soft subgrade. These variations in the law of pressure distribution disappear in any rational formulas for macadam design for the following reasons: A well-designed macadam road must not have much deflection under a moving wheel load, for the minute noticeable deflection occurs (so-called churning), the pavement starts to disintegrate, and either gets out of shape rapidly or completely goes to pieces. Some deflection is bound to occur, but the basic principle of good design requires variation in stone depth over different soils, so that the maximum wheel load produces a fairly uniform deflection at all points. This deflection must be small enough to prevent churning. If the road is properly designed with a uniform and safe deflection, the relation of depth to distribution area and the ratio of maximum intensity are not probably much affected by the character of the subsoil. At least it is known from practical experience that simple empirical formulae, which consider variations in wheel load, a fairly well-established relation between depth and intensity of pressure on the subgrade, and reasonable values for safe supporting power of soils, have been developed, and that such formulae have been given sufficiently hard and long enough continuous service tests to warrant their use as a basis of economic macadam design.

An old and simple rule will be used as the basis of a practical formula, namely, the Massachusetts rule of 1901: "The pressure is distributed through macadam and any ordinary gravel or boulder base at an angle of 45° with the horizontal, and the resultant maximum intensity of pressure on the subgrade amounts to the load at any point divided by the square of twice the depth of the pavement." While this is rather a rough-and-ready rule, its application produces as good results as any basis of comparison, provided it is slightly modified to consider width of wheel. For-

mula (1) makes such minor modifications. A comparison of Formula (1) with the French experiments (Table 72) is shown in graphic form in Fig. 124, and indicates essential agreement as far as practical results are concerned, with the added indication that formula (1) is on the safe side for the usual combinations of macadam top and boulder bases.

Research engineers are not likely to approve heartily of this formula, as it is not a very scientific product, but its simplicity,

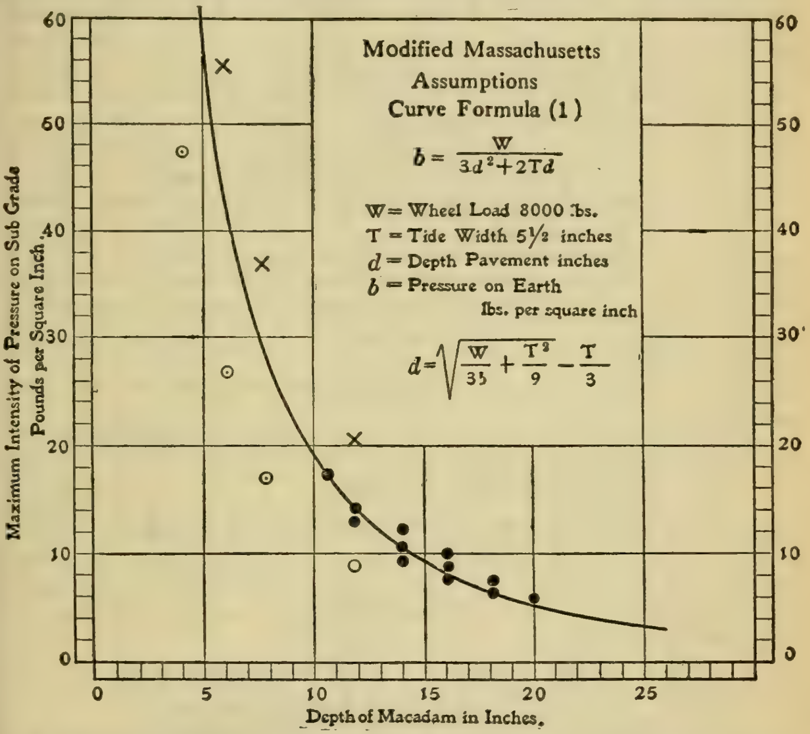


FIG. 124.—Graphic comparison of Formula 1 (solid curve) with French experiments recorded in Table 72 (plotted by crosses, circles and dots).

its essential agreement with experimental data, and the excellent results obtained in actual construction from its use are strong arguments in its favor.

Basic Assumptions (Formula (1)). *Area Uniform Maximum Pressure.*—A hypothetical area of uniform maximum pressure is determined by a line at an angle of 45° from the outer limits of wheel contact. This, of course, does not represent actual conditions, but it is on the safe side. The pressure caused by a wheel load is not uniformly distributed over the subgrade (see Figs. 122 and 123, p. 379). The maximum pressure occurs directly under the wheel and gradually fades away to nothing at a variable distance from the point of load. The assumption used gives the same total

resistance to the wheel load, but contracts the actual area of the subgrade receiving variable pressure to a hypothetical area over which the maximum pressure occurring directly under the wheel is considered as uniform. The essential correctness of the 45° limit of uniform maximum pressure can be seen from Figs. 122, 123, and 124. By this means the value for safe supporting power of soils can be used directly.

The area of maximum uniform pressure depends on the area of wheel contact, which depends on width of tire and length of contact along the road. The width of tire is a definite dimension, recognized and limited in statutory load regulations. The length of tire bearing along the surface is variable, depending on size of the wheel and on the type of tire and load. For steel-tired wheels it is small, probably not over an inch. For solid-tired heavy commercial trucks it is a larger value. Since the steel-tire load is liable to occur and the length of contact is variable for rubber tires, this dimension will be neglected and knife-edge contact for the full width of the tire will be used. This gives results on the safe side and, in effect, usually introduces a factor of safety of about 10 to 25%. It is also assumed that the wheel load is far enough from the edge of the pavement to get full distribution for the entire depth of pavement. Modifications for edge loading are considered in Formula (2).

The formulas for depth of macadam are developed on the basis outlined.

W = static wheel load, in pounds plus impact allowance.
T = width of tire, in inches.
d = depth of pavement, in inches.
b = maximum pressure on subgrade due to wheel load, in pounds per square inch.

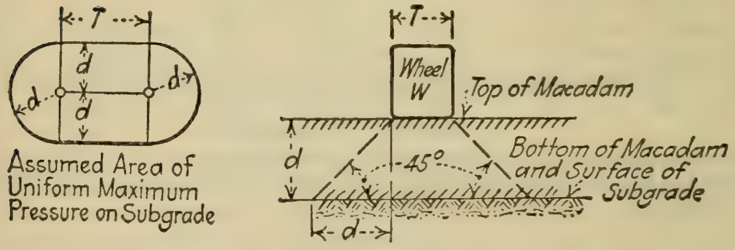


FIG. 125*A*.

Area of uniform distribution of maximum pressure $= \pi d^2 + 2dT$
$= 3.14\, d^2 + 2dT$
$= 3d^2 + 2dT$ for all practical purposes.

$$\left.\begin{aligned} b &= \frac{W}{3d^2 + 2dT} \\ d &= \sqrt{\frac{W}{3b} + \frac{T^2}{9}} - \frac{T}{3} \end{aligned}\right\} \qquad (1)$$

Modification of Formula (1) for Special Location of Wheel Loads.—A typical maximum-load condition is shown in Fig. 126 for an 18-ft. double-track road. This is a rare occurrence, as when trucks pass they want all the clearance they can get and they hug the edge of the road (Fig. 127).

These sketches indicate roughly that there is not much probability of enough overlap of pressure zones from adjacent wheels in the center of a road to produce a greater pressure than the maximum directly under the wheel for ordinary depths of macadam on

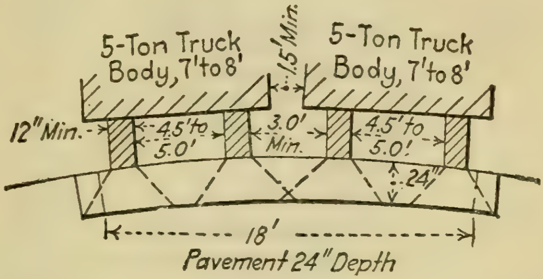


FIG. 126.—Location of passing vehicles for critical load in center of macadam.

ordinary soils; for extreme depth on very poor soils such an overlap may occur, but it would require a very unusual combination of unfavorable conditions to make this continuous enough to cause trouble.

On the side of the road, however, edge loading is very common and continuous on Class I roads, but it occurs only at intervals along the road and only at time intervals on roads of Classes II, III, and IV. This critical condition of side load must be considered

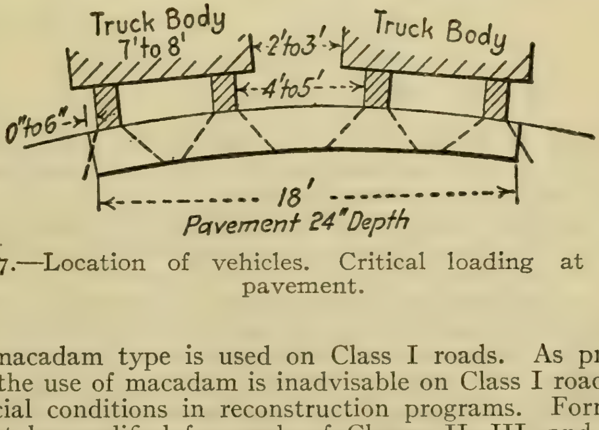


FIG. 127.—Location of vehicles. Critical loading at edge of pavement.

if the macadam type is used on Class I roads. As previously stated, the use of macadam is inadvisable on Class I roads except for special conditions in reconstruction programs. Formula (1) need not be modified for roads of Classes II, III, and IV, but probably should be modified for Class I roads.

Any modification is purely guesswork and is made more to point out and recognize the effect of critical loading on Class I roads than for any other reason. Under the worst possible conditions, elimi-

nating all distributing action by the shoulder material, the supporting area may be assumed as

$$2dT + \frac{\pi d^2}{2}, \text{ say, } 2dT + 1.5d^2.$$

This is probably entirely too low a value, and to approximate conditions and to give some value to shoulder support, the area will be assumed at

$$2dT + 1.5d^2 + \pi\left(\frac{d}{2}\right)^2$$

$$\text{say} = 2.25d^2 + 2dT.$$

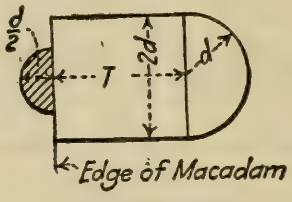


FIG. 128.

Using this value, Formula (1) becomes
For Class I traffic:

$$\left.\begin{aligned} b &= \frac{W}{2.25d^2 + 2dT} \\ d &= \sqrt{\frac{4W}{9b} + \frac{16T^2}{81}} - \frac{4T}{9} \end{aligned}\right\} \qquad (2)$$

For traffic of Classes II, III, and IV:

$$\left.\begin{aligned} b &= \frac{W}{3d^2 + 2dT} \\ d &= \sqrt{\frac{W}{3b} + \frac{T^2}{9}} - \frac{T}{3} \end{aligned}\right\} \qquad (1)$$

Utilization of Formulas (1) and (2) in Macadam-pavement Design.—To utilize these formulas, it is necessary to assemble the values for load, supporting power of soils, and to discuss the factor of safety desired. Load and distributing power of macadam when tight locked are reasonably certain. Live load will vary according to the traffic the road will have, but for all practical purposes it is safe to use the statutory limitation plus an allowance for impact. The values given on page 374 contain a small factor of safety. Dead load of the pavement itself can be safely disregarded except when dealing with muck or swampy foundation. The formulas developed for distribution of pressure assume the same distribution for all the usual combinations of base and top courses and disregard reduction in distributing power due to frost action for a short time in the spring. Figure 124 indicates that for the usual combinations

of base and top these formulas are on the safe side, but this factor is probably balanced by the unknown reduction in distributing power during the spring break-up. Safe soil-supporting power is the most indefinite factor in the problem. As this factor is largely a matter of personal judgment, the values assigned for supporting power of soil can provide the desired factor of safety in the result.

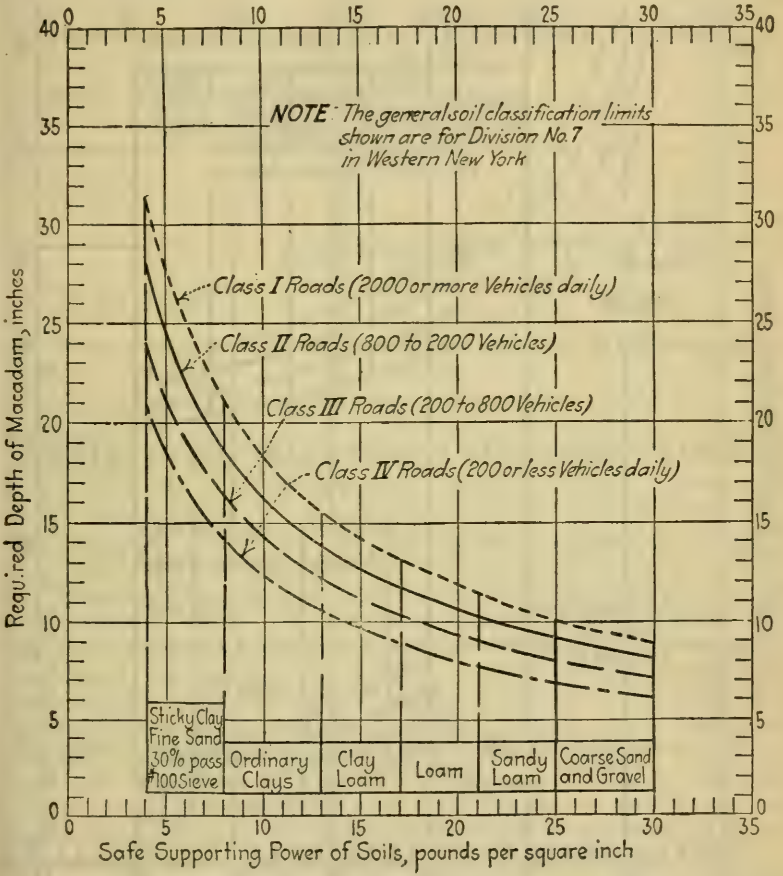
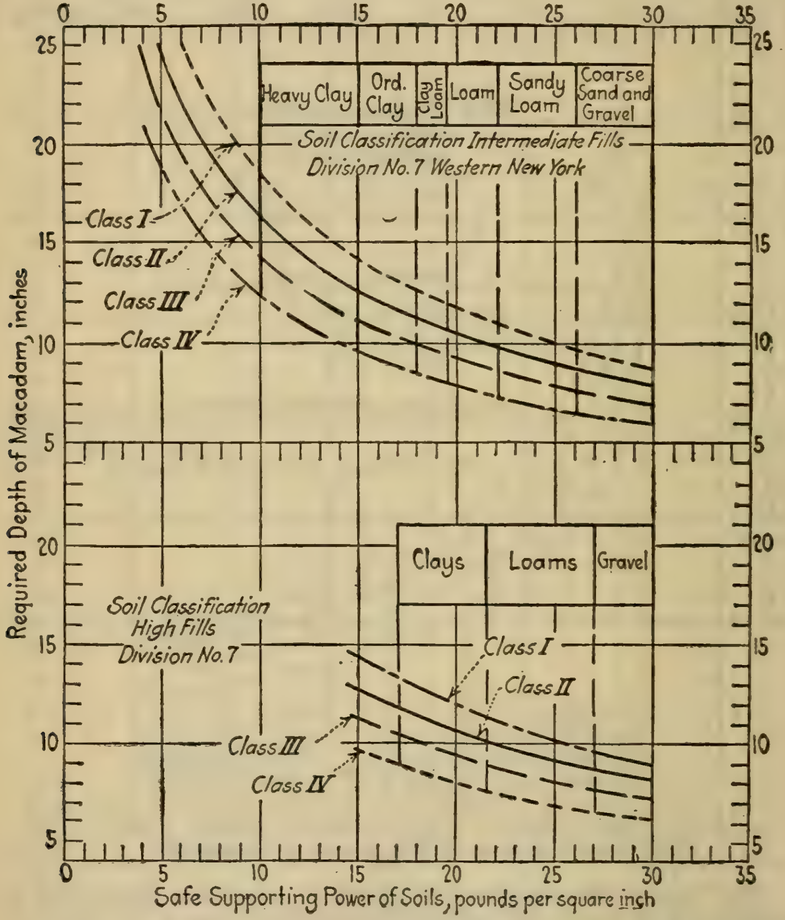


FIG. 129*A*.—Recommended depths of macadam pavements on different soils where the pavement is located either in cut or on fills less than 1 ft. deep.

The values given on page 377 were adjusted for use in conjunction with this formula; it will be noted that the values used for the extreme conditions of good and bad agree closely with the Massachusetts and French values. The intermediate values are based on experience in western New York for a number of years. The use of these values for districts similar to western New York will give reasonable results. There will be some spring failures, but not many, and for the balance of the year the factor of safety is high.

Figures 129, 130*A* and 130*B* show graphically the depths of macadam obtained by the use of Formulas (1) and (2) with the recommended live loads given on page 374 and the soil values given on page 377.

The suitability of these curves for any district can be easily determined by plotting on a chart the record of actual road failures



FIGS. 130*A* and *B*.—Recommended depths of macadam pavements located on fills. Intermediate fills (1 to 3 ft. deep). High fills (over 3 ft. deep).

for the district in question. If the curve derived from Formula (1) (using the local load limitation) is very much above the average run of actual blow-ups, it can be lowered to get a reasonable percentage of failure; that is, this curve should about fit the upper limit of depth for the usual failure on the different soils. A few exceptional cases can be disregarded. The data of actual road

failures should be charted in a similar way to the usual chart of storm intensity in deriving storm-sewer design assumptions. This method is illustrated by Fig. 131 (p. 388), which is a record of observations in western New York, 1907 to 1920.

Formulas (1) and (2) reduce to the following form if the design loading recommended on page 374 is used:

Class I roads:

$$d \text{ (depth macadam)} = \sqrt{\frac{48{,}000}{9b} + 28} - 5.3.$$

Class II roads:

$$d = \sqrt{\frac{12{,}000}{3b} + 16} - 4.$$

Class III roads:

$$d = \sqrt{\frac{9000}{3b} + 11} - 3.3.$$

Class IV roads:

$$d = \sqrt{\frac{7000}{3b} + 11} - 3.3.$$

These formulas are used in the preparation of Figs. 129, 130*A* and 130*B*.

Experience with Various Depths of Macadam in Western New York.—The first roads built in this section (from 1898 to 1902) were quite uniformly 6″ in thickness over all kinds of soils. This was admitted to be rather irrational design, but the cost had to be kept down and it was considered better policy to plan on more or less failure with consequent repair rather than spend more to insure against minor failure. As experience was gained, the depths were varied somewhat over different soils, but these depths were in all cases much less than are used today. The growth in motor traffic with heavier loads and more vehicles has resulted in the failure of most of these old thin macadams, and the old roads have been gradually strengthened by the addition of extra courses of stone to meet the increased loads. By observation of these successive thickenings, the State Department of Highways has had a very excellent opportunity of drawing reasonable conclusions as to the depths required for handling modern traffic on different soils.

There has, however, been no systematic official effort to gather these data in a complete and convincing manner, and what data are available are due to the individual efforts of a few of the engineers. Officially, the experience of 20 years has been thrown away as far as definite tabulated data in regard to economical macadam depths under different conditions go. This is very typical of the attitude towards highway work in many cases, and some executives have even said that they did not want to know too much about the economics of different types of pavements. This general attitude is being gradually discredited, and there are hopes that in time an effort will be made to record the number of square yards of different depths on different soils with the yearly percentages of

failure for the various depths and in this way gain some reliable means of balancing original cost against minor repair. This method has been used by various cities in determining economic depth of concrete foundations for street pavements.

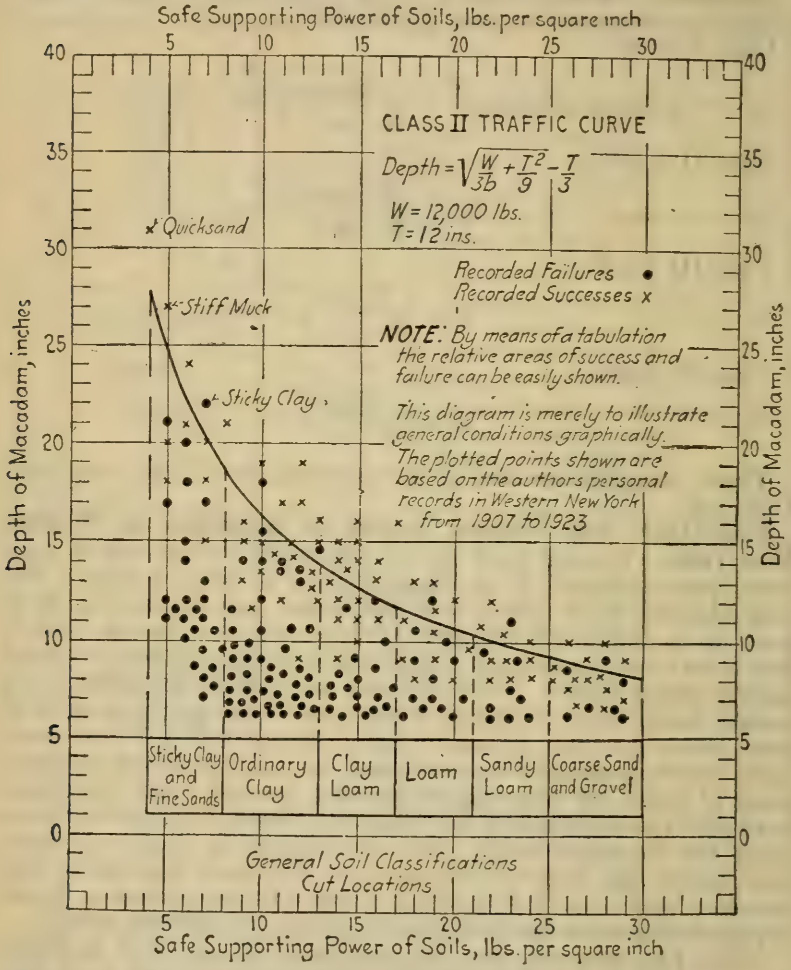


FIG. 131.—Comparison of theory with record of actual successes and failures.

The following statements summarize the experience and judgment of a number of the engineers of Division 4 who have kept records of successes and failures under the test of modern traffic, including army trucking during the war.

"Pavements 22″ thick laid on poor clay and stiff muck soils have in a few exceptional cases rutted badly under Class II traffic. Pavements 23 to 27″ thick under similar soil and traffic conditions have retained their shape and have required only minor repair. This represents the worst soil conditions

encountered in this territory. As a rule, a depth of 20″ even on very poor clay holds Class II traffic with only minor failures.[1]

"On coarse sand and fine gravels, we have cases where a 7″ depth is serving Class I traffic with no evidence of weakness, but these are exceptional cases. As a rule, 9″ is considered about the minimum serviceable depth for Class I on excellent soils.

"For loams, 7 to 8″ depths have in some cases lasted well under Class II traffic, but as a rule 10 to 12″ is considered necessary to avoid too much maintenance.

"For ordinary clays 9″ often lasts quite well under Class II traffic, but enough trouble has occurred even with 12″ depth on these soils to warrant 15 to 18″ as a reasonable design depth under Class II or III loading."

Current Practice in Macadam Depths (1922).—In order to coordinate this experience with other localities, Table 73 records the range in macadam depths used by other states. Figure 131 shows a graphic method of charting successes and failures.

TABLE 73.—RANGE IN MACADAM-PAVEMENT DEPTHS

State	Minimum depth on firm soils, inches	Maximum depth on poor soils, inches
New York	8 (gravel soil)	12–30 quicksand
Rhode Island	6	9–20
Indiana[a]	11	14 or more
Pennsylvania[a]	9	12 or more
West Virginia[a]	8	12 or more
Arizona	6	Whatever needed
Wisconsin[a]	8	12 or more
California	6	Whatever needed
Washington	7	12 or more

[a] The maximum depths given for these states do not indicate actual extreme maximums for short stretches of exceptionally poor soil conditions.

Effect of Soil and Total Depth on Selection of Foundation Courses for Macadam Pavements.—No matter what total pavement depth is required, the upper 3½ to 9″ are usually of the true broken-stone or broken-slag macadam. Below this macadam, either stony gravel, boulder base, or quarry-stone Telford can be used to get the total depth required with the least cost. If quicksand or wet clay is encountered, at least 6″ of cinders or gravel should be placed as the lowest layer in order to blanket the soil and prevent its working up into the stone courses. Above this either gravel or boulder base or Telford can be used, capped with the usual broken-stone bottom and top courses. In case gravel subbase is used for the entire depth of subbase, at least 5 to 9″ of macadam must be used for the cap, as it is not safe to produce a pressure of over 30 lb. per square inch on fine gravel without danger of rutting, and the object of the overlying macadam is to reduce wheel pressure to this value (see Fig. 130*A* gravel soils). If the gravel subbase is exceptionally coarse stony gravel, it is safe to reduce the macadam cap thickness to 4″ for Class IV roads and to

[1] For deep macadams, the upper 3½ to 7″ are usually broken-stone macadam with the balance of the depth coarse gravel, boulders, or Telford subbase courses.

8″ for Class I roads. If boulder or Telford base immediately underlies the macadam, the thickness of the macadam can be reduced to 3½ to 5″, as the boulder base has better supporting power than the gravel for direct concentrated loading; that is, the object of macadam cap over the boulder base is to smooth the road for the use of traffic.

The line of pressure distribution is about the same through boulder base or gravel, with the evidence slightly in favor of the gravel.

The use of gravel for subbase does not increase the total necessary pavement depth, but it does increase the necessary thickness of the true macadam type of surfacing (see Figs. 132 and 133).

For any depth up to 8″ the true macadam top and bottom courses are generally selected. For greater depths, any combination can be used, keeping the depth of the macadam capping to the minimum safe depth for the type of subbase used.

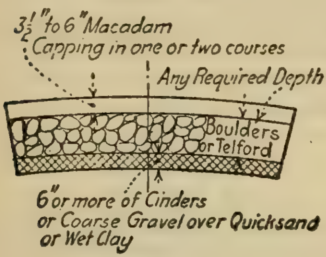


FIG. 132.

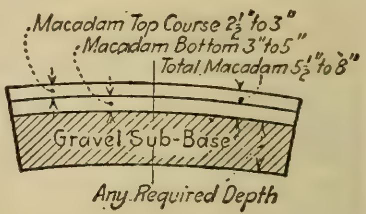


FIG. 133.

FIGS. 132 and 133.—Effect of type of base on thickness of macadam surface.

Recommended Depths.—From the foregoing theoretical and practical data the following recommended depths are derived (Table 74). Such recommendations are intended for use in localities subject to severe winters and for the design loading outlined in Table 68 (p. 374). They are intended as a guide only, to indicate the trend of design practice. There is no intention of creating the impression that they are necessarily the best solutions for all cases, but they can be used with assurance of reasonable success in case local practice has not been crystallized by long experience.

The foregoing discussion shows that, while in a strict sense macadam-pavement depth is not susceptible to true engineering design, it is susceptible to a rational analysis which tends to produce better-balanced results than the purely hit-or-miss methods that have been more or less in use for the past 15 years. *The flexible type of pavement, is generally the most economical type for 90% or more of the road mileage in most localities, and for this reason rational design is essential.*

Asphaltic-concrete and Block Surfacing on Macadam Bases.—This type of road is a desirable design where an old, firm, well-consolidated macadam road needs a better type of surface. *Asphaltic concrete or any high-type block surface should never be laid on new*

TABLE 74.—RECOMMENDED TOTAL DEPTHS OF FLEXIBLE PAVEMENTS IN LOCALITIES SUBJECT TO SEVERE WINTERS (IN INCHES)

Soil	Location of road		
	In cuts or on shallow fills less than 1′ deep	On intermediate fil s 1 to 3′ deep	On high fills over 3′ deep
Class I traffic (over 2000 vehicles daily, 10-hr. count in summer) (Macadam not usually economical on Class I roads)			
Coarse sand and fine gravel	9–10	9–10	9
Loams	10–14	10–12	10
Ordinary clays	15–21	12–16	11
Heavy clays and fine sands	22–30	14–18	13
Class II traffic (800 to 2000 vehicles daily, 10–hr. count in summer)			
Sand and gravel	8– 9	8– 9	8
Loams	9–12	9–11	9
Ordinary clays	12–18	11–15	10
Heavy clays and fine sands	18–28	13–16	12
Class III traffic (300 to 800 vehicles daily, 10–hr. count in summer)			
Sand and gravel	7– 8	7– 8	7
Loams	8–10	8– 9	8
Ordinary clays	12–16	9–14	9
Heavy clays and fine sands	18–24	12–15	11
Class IV traffic (less than 300 vehicles daily)			
Sand and gravel	6– 7	6– 7	6
Loams	7– 9	7– 8	7
Ordinary clays	10–15	8–12	8
Heavy clays and fine sands	15–22	10–14	9

macadam, as it is impossible to get complete consolidation of macadam without the added help of traffic pounding.

Firm macadam bases having the thicknesses previously discussed make an ideal foundation for asphaltic concretes and block with mastic fillers, as temperature cracks are largely eliminated. Temperature cracks are the main difficulty encountered where these pavements are laid on concrete foundations. Very excellent results have been obtained in Rochester, N. Y., where this type of construction has been used extensively.

The general conclusion to be drawn is that where an old, firm macadam of adequate depth has been constructed in the past it makes an excellent base for a higher-type surfacing. For the quick construction of an asphalt or brick surface on a heavy-traffic unimproved road the concrete base is the most feasible design. It is well to bear in mind,

however, that, while from a practical standpoint the use of a concrete base on a new grading is the best solution for quick results, expensive failures often result from the construction of concrete on new fills or over sewer trenches that have not had time to settle; it is desirable to wait at least a season after a road is graded before placing a rigid pavement. This delay is rarely possible, but if it is feasible the macadam-base type has the advantage, as the macadam base gives good service to traffic while it is consolidating and eventually produces a more satisfactory base than concrete except for exceptionally heavy volume and unit traffic (Class I roads). Where asphaltic concrete is used on top of macadam, the depth of asphaltic surface can be considered as equivalent to an equal depth of macadam. On this basis Table 74 is directly available for computing required total depths.

STRENGTH DESIGN, RIGID PAVEMENTS

Rigid-pavement Design.—Rigid pavements are more difficult to analyze for strength design than the macadam type, but an approximation can be derived. The following discussion is not a scientific analysis in any sense of the word, as this is impossible at the present stage of experimental knowledge. It is desirable, however, to develop empirical formulas which are based on available experimental data coordinated with actual traffic tests.

Considerable progress has been made in the last few years towards a fairly well-balanced design of strength. Investigations in regard to temperature warping, fatigue of materials, soil support, etc. have established fairly definite general principles which have modified the old-style design to advantage. These modifications include reduction in unit width of monolithic-type slabs, increase in the strength of the outer edge of narrow rural highway pavements, and improvement in quality and manipulation of materials. Theory developed from experimental research seems to have been essentially verified by traffic tests, and while there is considerable range for judgment in assigning values to the various factors in the formulas, there is no serious disagreement in regard to essentials. *A discussion of formulated design is given with the idea of bringing out the factors of the problem for the student rather than of providing hard-and-fast standards of designs.* As a matter of fact, a careful analysis of any theoretical discussion of pavement design shows plainly that experience with actual traffic tests is the most reliable basis for action. Table 86 (p. 426) gives the summarized recommendations based on both theory and practice. This table is of definite practical value.

Design Fundamentals (Rigid Slabs).—As outlined on page 366, rigid pavements are designed to bridge over small areas where there is either partial or complete loss of soil support. If large areas of the subgrade settle materially, the pavement fails; it is necessary to provide enough slab strength to bridge all areas of poor soil support which ordinarily occur under the usual construction conditions, but the cost of designing a pavement for exceptional areas of settlement

is prohibitive.[1] It is, of course, impossible to determine exactly what size these commonly occurring weak areas will be, and it is necessary to assume some maximum condition of loss of soil support for which provision will be made. The so-called corner-load formula, developed in 1919 by the Illinois Highway Department, Clifford Older, Chief Engineer, seems to afford a practical mathematical basis of comparison of slab strengths ordinarily needed to produce economical pavements which will not have too great percentages of weak areas. *This formula should, however, be used as an index of relative strength rather than as a basis of absolute strength, as it eliminates soil support as a direct factor in the computations.*

Observed pavement failures indicate the predominance of corner-area weakness. Recent experiment has determined that soil contact under corners and along the edges of slabs is quite commonly completely lost, or at least reduced to negligible value. This condition is due to temperature warping, to compression of subgrade due to edge deflection of slabs under heavy traffic, and to increase in the moisture content of the subgrade soil by ground-water seepage and the seepage of surface water through cracks and down through ruts along the edge of the pavement.[2] The extent and the frequency of serious loss of soil support can be reduced by narrowing the width of slabs, by constant sealing of surface cracks, by well-constructed and maintained shoulders, and by effective underdrainage, but even with the greatest care in these particulars soil support is unreliable at corners. These recognized conditions led to the development of the corner-load formula. It is expressed as

$$d = \sqrt{\frac{JW}{S}},$$

in which d = depth of slab, in inches.
W = design wheel load, in pounds.
S = maximum allowable design tension value, in pounds per square inch.
J = variable factor determined by load distribution and location of critical load.

Soil support is disregarded as a direct factor in the computations.

While all the factors W, S, and J are more or less indefinite, actual road service tests are rapidly eliminating any wide range of uncertainty. The formula can be used directly for most cases with good results, but it has more real value as an index of relative strength than as a basis of design of absolute strength on account of complete disregard of soil support. The results obtained by the formula are susceptible to percentage modifications due to reasonable allowances for normal conditions of some soil support. Such modifications depend on direct traffic tests for normal conditions. The impossibility of exactly determining the value of soil

[1] Some efforts have been made to develop an economical design on the basis of pillar support extending below frost line. This basis of design simplifies the design stress problem, but it is not likely that any system of bridge-floor slab design can compete economically with a base partially in contact with the earth subgrade.

[2] "Bates Experimental Road" *Bulletins*, Illinois Department of Highways.

support is the stumbling block in applying scientific design to any type of pavement, either rigid or flexible. The formula is developed as follows:

The Corner-load Formula.—Rigid pavements are considered as a series of slabs. This is essentially correct, for most modern monolithic pavements are constructed with well-defined joints, and most two-course pavements which may be originally constructed as a continuous slab are later broken up by temperature and traffic action into a series of slabs. Mr. Older is quoted as follows:

"*Corners Critical Points.*—It may be safely stated that cracks and joints, *if properly cared for*, affect the life of a rigid slab only as they may affect its strength or load-carrying capacity.

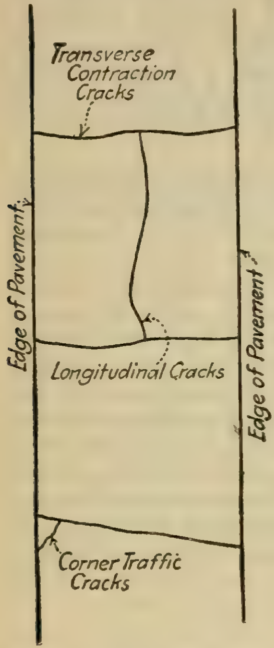


FIG. 134.—Typical cracks.

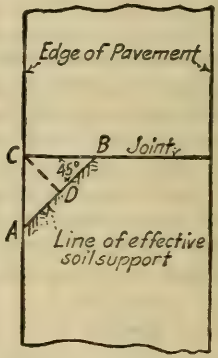


FIG. 134*A*.—Corner load formula diagram.

"It is not necessary to apply mathematical calculations to develop the fact that a load applied near the center of a comparatively large unbroken pavement slab would produce much lower stresses therein than would be produced were the same load applied at or near the edge of the same slab. Further, it is evident that a load applied at the edge of an unbroken slab would not produce stresses as great as those produced by the same load placed at a corner formed by cracks or joints. It is obvious that these are bending stresses which must be withstood by the resisting moment of the slab.

"Regardless of the supporting capacity of the subgrade, it is the corners formed by intersection of cracks or joints with each other and with the edges of the pavement that constitute the weak points of rigid slab pavements. On the Illinois roads which carry truck traffic many broken corners have been observed in all types of rigid pavements, and only in a single instance has a traffic break been observed that was not readily traceable to the piecemeal breaking down of corners or narrow strips formed by longitudinal cracks making acute angles with the edge of the slab. The exception was an asphalt top pavement on a 1:3:5 concrete base 4″ thick at the sides and 5″ thick in the center, which broke into small pieces under excessive truck traffic. An examination of the base showed that its transverse strength had been exceeded even in the center of the slab. No concrete slab 6″ or more in thickness has broken except at corners or except over trenches or other causes of localized settlement.

"Until we are able to control completely the cracking of rigid slabs it seems obvious that we must design the entire slab to carry the imposed loads at the weak point—*the corners.*"

The last paragraph of Mr. Older's statement must not be construed to mean that pavements must be of uniform thickness throughout, as this would result in unbalanced and uneconomical design; that is, the location of corners (such as along the edge of the pavement as compared with interior corners) and other factors later discussed have considerable bearing on the stress produced by normal wheel loads. If due allowance is made for the location and special conditions of load application at different kinds of corners, this test (corner resisting moment) can be used quite successfully in the design of pavement strength.

The relation of traffic load to necessary corner resisting moment of the slab is quite simple, assuming complete loss of soil support for a small area under the corner, load applied at extreme corner, intersection angle of joints, sides, and cracks 90°.

The resisting moment of the slab along the line AB (Fig. 134A) is

$$R = \frac{SI}{\frac{d}{2}} = \frac{Sbd^3}{6d} = \frac{Sbd^2}{6},$$

where R = resisting moment of slab.
S = allowable tensile stress in outer fiber.
I = moment of inertia of the section along line $AB = \frac{bd^3}{12}$.
d = depth of slab, in inches.
b = distance AB, in inches.

The load moment is expressed as load L in pounds, times the moment arm CD in inches. At right-angle corners the distance CD is always one-half of $AB = \frac{b}{2}$ no matter what distance CD becomes. This gives a constant relation between the load moment and resisting moment, regardless of variations in the size of areas of no support under corners.

$$\text{Load moment } M = \frac{Lb}{2}.$$

The load moment and the resisting moment must be the same where soil support is completely lost.

$$\frac{Lb}{2} = \frac{Sbd^2}{6}$$

$$d^2 = \frac{3L}{S}$$

$$d = \sqrt{\frac{3L}{S}}.$$

For convenience, this is modified to $d = \sqrt{\frac{JW}{S}}$ where W equals the design wheel load (discussed on p. 374), J equals 3 × the decimal part of W, which can be considered as applied at the extreme corner, and S equals the maximum allowable design tension value for the material or combination of materials making up the road slab.

Utilization of Corner-load Formula in Design.—The successful use of this formula depends on the determination of reasonable values for tensile strength of the slab S, wheel load W, load distribution at joints in conjunction with location of load J, and soil-support modifications which control the factor of safety of the finally adopted depth. A short discussion of each factor follows. They will then be assembled for the different types of pavement and a table prepared which shows roughly the effect of load on depth and compares the depths required for the different types of pavement under specified legal load limits.

Design Values for Tensile Strength S.—Pavement slabs are constructed of plain concrete without any reinforcement, concrete containing small percentages of imbedded steel, combinations of cement concrete and brick with a fairly firm bond (so-called monolithic brick), and combinations of bituminous concrete or block surfaces on cement-concrete bases with a well-defined plane of weakness between base and surface courses. All pavement slabs subject to bending stresses fail from tension weakness. It is well established that it is uneconomical and impracticable to attempt to reinforce thin pavement bases with enough steel to take full advantage of the compressive strength of concrete. The tensile resistance of concrete can be raised slightly for small areas, such as corners, by means of bar reinforcement. Construction imperfections in mix and materials can be equalized by light mesh, which acts as a fibrous tie, and the use of small amounts of steel in this way permits a rise in allowable design stress. If failure occurs it is always a tension failure. It is therefore necessary to consider only the safe tensile strength of the materials or combination of materials in computing slab strength.

In adopting values for tension to be used in the corner-load formulas, it is desirable to use the highest reasonable value, as there is no objection to a small percentage of pavement failure. The values given at the close of this portion of the discussion have been tentatively adopted, as their use in conjunction with the distribution factors and wheel loads recommended seem to result in pavement thicknesses which have proved to be adequate under tests of modern traffic. These values are somewhat higher than many authorities advise.

The discussion of design tension values is based on the modulus of rupture of materials. The term "modulus of rupture" is defined as follows by Hool and Johnson:

"The transverse or beam strength of granular brittle materials like mortars and concretes is best expressed by the modulus of rupture. The modulus of rupture is the apparent stress in the extreme fiber of a transverse test specimen under the load which produces rupture. For specimens of rectangular section of breath b and depth d, loaded centrally on a span L, the breaking load being W, the modulus of rupture is computed by the formula

$$\text{Modulus of rupture} = \frac{3WL}{2bd^2}.$$

"The extreme fiber stress thus computed is not the actual fiber stress, because the formula involves the inaccurate assumption that the material deforms elastically for all stresses up to rupture. The comparative relations between results are not affected by this inaccuracy of the formula, however,

when the tests compared are made upon specimens of similar material, because the computed values of the modulus of rupture are very nearly proportional to the actual stresses.

"Since the extreme fiber stresses on the tension side and on the compression side of a beam of homogeneous material are equal, the tensile strength of mortar or concrete is only a small fraction of the compressive strength, the transverse strength of mortar or concrete is almost wholly dependent upon the tensile strength. The modulus of rupture found in transverse tests will invariably be considerably in excess of the tensile strength, however, because the computed stress in the extreme fiber considerably exceeds the actual stress."

Modulus of Rupture of Plain Concrete.—For a number of years it has been quite well established that loads producing computed stresses exceeding 50 to 60% of the modulus of rupture of plain concrete result in permanent deflections. Recent experiments by the Illinois Highway Department on the effect of repetition of load on rupture have shown that loads producing computed stresses of 37% of the modulus of rupture can be repeated 1,000,000 times without causing failure; loads producing stresses of 53% of the modulus of rupture were repeated from 40,000 to 200,000 times before rupture occurred; loads producing stresses of 70% of the modulus of rupture broke the test piece after repetitions of from a few hundred to a few thousand applications. To prevent rupture due to unlimited repetition of load, it is therefore desirable to adopt a design stress of about 45% of the modulus of rupture.

The modulus of rupture of concrete pavements or bases has considerable range in value, depending on the mix, age of concrete, and perfection of construction operations. It would be impracticable and uneconomical to attempt to use a design tension value which would prevent occasional failure of fresh concrete under repeated heavy loading.

New pavements are generally opened to traffic in 14 to 28 days after construction. It is necessary to provide enough strength at this time to prevent corner breaks due to the loading produced by normal traffic. The pavement must be able to handle immediately a few applications of the maximum permissible wheel load, but it is not rational to make the pavement strong enough at this stage to stand repeated rapid applications of the maximum legal load, nor is it likely that this condition will occur except under very unusual conditions.

The pavement must be strong enough when first opened to permit continual application of the loads produced by the usual vehicle, but these loads are far below the legal maximum. The maximum wheel pressure permitted by law is produced only by a very small percentage of the vehicles operating on the usual road. These vehicles in passing over the pavement apply their load only at critical corner points to a very small percentage of the slab corners. It is not likely that a single slab corner has the maximum legal load applied to the extreme corner with greater frequency than, say, one one-hundredth of 1% of the number of vehicles using the road The concrete rapidly gains strength with age, so that, when a design tension value is adopted high enough to prevent rupture at the 28-day age for the maximum load without considering the effect of repetition, the probabilities are all in favor that it will gain

strength fast enough to take care of the maximum loads as they occur.

A value of about 65% modulus of rupture is, therefore, recommended for 28-day concrete in conjunction with the maximum legal wheel load. This means that the stress produced by the ordinary light vehicles is less than 50% of the modulus of rupture at 28-day age and can be repeated indefinitely even at that stage. Within 6 months or a year the concrete will probably gain sufficient additional strength to stand indefinite repetitions of the maximum legal load. If some corners break during the first few months, they can be repaired under the item of minor repair. For exceptional roads carrying a large volume of heavy trucking, it is, perhaps, desirable to reduce the design tension values somewhat, or to insist on longer ageing before the road is opened to traffic.

The following tabulation shows the approximate ratio of the design stress recommended for 1:1½:3 concrete to the modulus of rupture at 28 days, 6 months, and a year.

Recommended design tension value	Approximate ratio of recommended stress to modulus of rupture		
	28 days	6 months	1 year
400 lb. per square inch, ...	65%	50%	45%

The ratio of modulus of rupture to compressive strength (28-day) determined for ordinary road concrete mixes on 6 by 12″ cylinders is approximately 23% (see Table 75).

The tabulation below gives the recommended values for S tension to be used in the corner-load formula for plain concrete pavement and base design:

Adopted Values (S) Design Tensile Strength Value for Plain Concrete Pavements and Pavement Bases

1:1½:3 mix	400
1:2:4 mix	360
1:2½:5 mix	320
1:3:6 mix[1]	280

[1] Recent tests (1921) by the Bureau of Public Roads indicate that the strength of 1:3:6 concrete tested for beam action is about 80% of the strength of 1:1½:3 mix, while the ratio of direct compressive strength of these mixes is 1:2. The adopted values use a ratio of 70% for beam action.

Tables, 75, and 75A give reliable test values of the modulus of rupture and serve as the supporting data for the recommended values.

Table 76 compares direct tension with modulus of rupture.

(*Bulletin* 11, *Lewis Institute Chicago, Prof. Duff A. Abrams*)

Aggregates: sand from Janesville, Wis., and pebbles from Elgin, Ill. Aggregates of *different size* were obtained by separating sand and pebbles into various sizes and recombining as shown by sieve analyses in Table II and Fig. 1. *Different gradings* of aggregates were produced by mixing sand (0 to No. 4) and pebbles (No. 4 to 1½") in different proportions.

Mix, 1:4 by volume. Relative consistency, 1.10. Specimens tested damp. Each value is the average of five tests made on different days.

Ref. No.	Aggregate		Water-ratio of concrete	Modulus of rupture of beams, pounds per square inch				Compressive strength 6 by 12" cylinder, pounds per square inch				Modulus of rupture, per cent of compression			
	Size	Fineness modulus		7 d.	28 d.	3 m.	1 y.	7 d.	28 d.	3 m.	1 y.	7 d.	28 d.	3 m.	1 y.
Effect of Size of Aggregate															
36	0–16	1.95	1.29	95	160	255	340	270	620	1,190	1,600	35.2	25.8	21.5	21.2
37	0–8	2.17	1.25	95	195	320	370	360	850	1,470	1,860	26.4	23.0	21.8	19.9
38	0–4	2.45	1.20	125	250	370	425	430	1,010	1,620	2,100	29.4	24.8	22.8	20.2
39	0–⅜	4.00	0.98	290	455	595	640	1,040	2,110	2,930	4,490	27.9	21.6	20.3	14.3
40	0–¾	5.00	0.87	365	560	730	775	1,290	2,650	3,650	4,890	28.3	21.2	20.0	15.9
41	**0–1½**	**5.65**	**0.82**	**420**	**550**[a]	**810**	**880**	**1,410**	**2,580**[a]	**3,590**	**5,000**	**29.8**	**21.3**	**22.6**	**17.6**
			Aver.	230	360	510	570	800	1,640	2,410	3,320	29.5	22.9	21.5	18.2
Effect of Grading of Aggregate															
29	0–1½	3.00	1.11	165	255	410	450	620	1,290	1,640	2,330	26.6	19.8	25.0	19.3
30	0–1½	4.00	0.98	230	390	505	570	950	2,000	2,550	3,230	24.2	19.5	19.8	17.7
31	0–1½	4.50	0.93	285	485	610	645	1,090	2,190	2,750	3,830	26.2	22.2	22.2	16.9
32	0–1½	5.00	0.87	325	505	660	710	1,160	2,410	3,580	4,510	28.0	21.0	18.4	15.8
33	0–1½	5.25	0.85	365	555	735	820	1,320	2,940	3,810	5,340	27.7	18.9	19.3	15.4
41	**0–1½**	**5.65**	**0.82**	**420**	**550**[a]	**810**	**880**	**1,410**	**2,580**[a]	**3,590**	**5,000**	**29.8**	**21.3**	**22.6**	**17.6**
34	0–1½	6.00	0.78	405	600	735	825	1,300	2,250	3,310	4,400	31.2	26.7	22.2	18.8
35	0–1½	6.25	0.77	385	590	730	865	1,140	1,990	2,840	4,080	33.8	29.6	25.7	21.2
			Aver.	320	490	650	720	1,120	2,210	3,010	4,090	28.4	22.4	21.9	17.8

NOTE.—Ordinary concrete pavement mixture shown in black-faced type (Reference 41).

[a] Average of 25 beam tests and 115 cylinder tests.

TABLE 75*A*.—TRANSVERSE STRENGTH OF MORTARS AND CONCRETES
(*Tests of William B. Fuller*)

Proportions by weight, cement, sand, stone	Proportions by volume, cement, sand, stone	28-day age. Modulus of rupture, (pounds per square inch)		
		Maximum	Minimum	Average of 6
1:1: 2	1:1.17: 2.06	798	646	710
1:1: 3	1:1.17: 3.09	732	573	656
1:2: 4	1:2.34: 4.12	480	399	439
1:2: 5	1:2.34: 5.17	413	349	380
1:3: 5	1:3.51: 5.17	308	262	285
1:3: 6	1:3.51: 6.21	246	213	226
1:4: 8	1:4.68: 8.25	158	156	157
1:6:10	1:7.02:10.34	91	87	89

Table 76 compares the value of direct tensile strength tests with modulus of rupture.

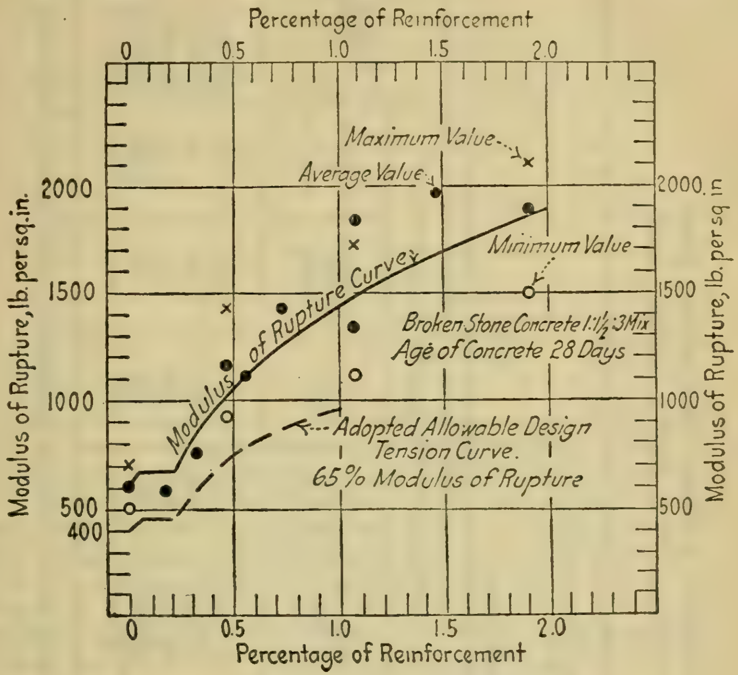
TABLE 76

Mix	Ultimate tensile strength, pounds per square inch	Modulus of rupture, pounds per square inch
1:1½:3	300–450	500–700
1:2: 4	250–350	400–600
1:2½:5	200–300	350–450
1:3: 6	150–250	250–400

Modulus of Rupture of Reinforced Concrete.—The proper use of steel in road design is discussed on page 465. It is sufficient to note at this point that light mesh weighing from 0.25 to 0.65 lb. per square foot has been found useful in raising the average strength of the concrete throughout the slab, and that corner-bar reinforcement of sufficient area to raise the modulus of rupture materially at such points is common practice.

Experimental data on the effect of small percentages of steel on modulus of rupture are very meager. Experiments by the Bureau of Mines, Lewis Institute (Professor Abrams), and at Cornell give some basis for assumptions in this matter, but the experiments do not cover a very wide range of size and spacing of steel bars or wire mesh and are not conclusive as yet (see Tables 77*A* and 77*B*). The results indicate that light bar reinforcement having an effective area of less than two-tenths of 1% has practically no effect in increasing the modulus of rupture of the beam. Experience, however, shows that light mesh weighing about 0.25 to 0.4 lb. per square foot and having an effective area of about five-hundreths of 1% apparently has considerable effect in reducing corner cracks. This is probably due to its action as a fibrous tie in equalizing construction imperfections. The use of even the light mesh seems to warrant a slight increase in the value of *S* for infrequent internal crack corners held in close contact by longitudinal side-bar rein-

forcement. The use of corner-bar reinforcement having an effective area of 0.2% or more has a decided value as determined by both experiment and practice. The effect of different percentages



Percentage Reinforcement	Adopted Allowable Tension Value (S) 1:1½:3 Concrete
0.0	400 lbs. per sq. in.
0.1	460 " " " ".
0.2	470 " " " "
0.3	580 " " " "
0.4	670 " " " "
0.5	760 " " " "

FIG. 135.—Effect of steel reinforcement on modulus of rupture of concrete.

of reinforcement on modulus of rupture and the tentative recommended values for *S* tension are shown in Fig. 135. These values are based on Table 77.

TABLE 77*A*.—EFFECT OF NUMBER OF STEEL REINFORCING BARS
(*Bulletin* 11, *Lewis Institute Chicago, Prof. Duff A. Abrams* 1922)

Beams: Depth, 7″; width, 10″; span, 36″.

Longitudinal reinforcing bars were spaced equally across the width and 1″ from the bottom of the beam. The total depth of beams varied from 6.9 to 7.1″.

Mix, 1: 4 by volume. Aggregate: sand and pebbles graded 0 to 1½″.

Relative consistency of concrete, 1.10; water ratio, 0.82.

Age at test, 28 days.

Specimens tested damp.

Each value is the average of five tests made on different days.

Compressive strength by 6 by 12″ concrete cylinders (average of 115 tests) was 2580 lb. per square inch.

Reference number	Number of ⅜″ round steel bars	Percentage of steel	Total load on beam, pounds	Computed stresses, pounds per square inch					Type of beam failure
				Tension in steel	Compression in top fiber	Bond	Shearing unit stress	Modulus of rupture	
7, 8	0	None	7,870[a]	......	.....	...	70	550[a]	Tension
59	1	0.18	7,850	73,000[b]	1,470[b]	570	70	560[b]	Tension
60	2	0.36	10,390	49,400[b]	1,460[b]	380	90	730[b]	Tension
61	3	0.54	15,010	49,100[b]	1,850[b]	380	140	1,085[b]	Tension
62	4	0.72	19,640	48,900[b]	2,190[b]	380	180	1,435[b]	Diagonal shear
63	6	1.09	25,820	43,800[b]	2,160[b]	340	240	1,885[b]	Diagonal shear
64	8	1.46	28,060	36,800[b]	2,530[b]	290	270	1,990[b]	Diagonal shear

[a] Average of 25 beam tests.

[b] Tension in concrete not considered in computing steel stress. Steel not considered as taking stress in computing modulus of rupture.

TABLE 77B.—RECORD OF TESTS AT CORNELL UNIVERSITY ON REINFORCED-CONCRETE BEAMS 5 × 7″, SPAN 4.0′ CENTRAL LOAD (AGE 28 DAYS)

Proportions by volume	Per cent of reinforcement	Maximum	Minimum	Average
Gravel concrete				
1.5	0.47	887	722	844 (4 tests)
1:5	1.07	1262	826	1032 (4 tests)
1:5	1.89	1300	1020	1175 (4 tests)
Crushed-stone concrete				
1:1½:3½	0.47	1430	916	1159 (6 tests)
1:1½:3½	1.07	1720	1123	1344 (6 tests)
1:1½:3½	1.89	2100	1500	1880 (6 tests)

Even with considerable more experimental data, the effect of steel in actual design would be open to uncertainty for the following reasons: Road slabs are so thin that even small variations in location of the steel upsets its theoretical effect as regards tension. Even with the most intelligent labor and inspection, considerable variation occurs, so that the net practical value of steel as a tension. reinforcement is open to considerable uncertainty. For the thicker slabs, 7 to 8″, reasonably close assumptions can be made. These depths give bars some chance actually to work. For slabs less than 7″ deep steel is of little value in raising tension. In these slabs its value is confined to equalization and contact uses, as is later discussed. For the purposes of this discussion the relation between depth of slab and theoretical tensile effectiveness of steel is assumed as follows:

TABLE 78

Depth of slab, inches	Assumed effectiveness S	
	Mesh reinforcement, per cent theoretical[a]	Corner bars, per cent theoretical
7½ or more	100	100
7	100	90
6½	80	60
6	50	0

[a] Light-mesh reinforcement can be safely placed nearer the surface of the concrete than ½ or ⅝″ bar reinforcement.

The actual value of steel is really more a matter of cut and try than it is of theoretical design, but these statistics serve as an basis for judgment.

Wheel-load Factor W.—The wheel loads were discussed on page 373. The reader is referred back to that data, which recommended

the design loads shown in Table 79 for Class I and II traffic. These recommended design wheel loads include an allowance for impact and apply to districts in which the gross vehicle load is limited to 28,000 lb.

TABLE 79.—TABLE OF RECOMMENDED DESIGN WHEEL LOADS FOR DISTRICTS HAVING A SINGLE-VEHICLE, 28,000-LB. LEGAL MAXIMUM LIMIT (CLASS I AND II TRAFFIC)

Type of pavement	Design wheel[a] load W, pounds
Asphaltic concrete on cement-concrete base..........	12,000
Asphalt block on cement-concrete base................	14,000
Plain or reinforced cement concrete	14,000
Brick (cement-grout) concrete base..................	14,000
Monolithic brick..	14,000
Brick (bituminous-filled) bit-sand cushion..............	14,000
Brick (bituminous-filled) cement-sand cushion..........	15,000
Stone block..	16,000

[a] The differences are due to variation in impact allowance for different surfaces. See page 373.

Figures 138 to 143, which show graphically the theoretical depths obtained from the use of the corner-load formula, consider a range of design wheel load from 6000 to 20,000 lbs. As a rule, 9000 lb. is the least design load applicable to actual traffic conditions and 16,000 lb. the maximum. There are unusual cases, however, where 20,000 lb. load does occur today (1922, Massachusetts Traffic Report). Such loads violate legal statutes and their occurrence shows the necessity for police regulation unless adequate depth provision is made for their occurrence.

Location and Distribution of Load at Joints J.—Both the location and the distribution of loads affect the value of J (effective load applied at extreme corner of slab).

Critical Location of Load.—There are two general classes of slab corners, exterior and interior (Fig. 136). Wheel loads can be applied very close to the extreme corner along the outer edges of pavements with earth shoulders. It is impossible to apply the full wheel load at interior corners closer than about 6″ from the extreme point, provided the adjacent slabs are at the same elevation. This means that it is not possible for the load moment to be as great at interior corners as along the outer edge of pavements having earth shoulders. This condition in conjunction with other factors later discussed indicates in a general way that monolithic rural highway pavements constructed without raised curb edges should be designed stronger along the outer edge than along central joints. This conclusion is borne out by observed failures, fewer of which occur along central joints than along the outer edge. Recent designs recognize this fact by specially strong outer-edge design (see p. 455). City-street pavements with raised curbs have only one class of corner, namely, interior classification.

The exact effect of this difference in location of load on values for J is not known, but a rough approximation can be made. Corner cracks rarely start at more than 30 to 36″ away from the corner point, and generally at less distance. If 36″ is assumed as extreme distance, a difference of 6″ in moment arm would reduce the load moment about 15% for interior corners, which is a conservative allowance. The finally adopted values for J may well be about 15 to 20% less for interior than for exterior corners. Distribution of load at joints is, however, the main factor in determining reasonable values for J.

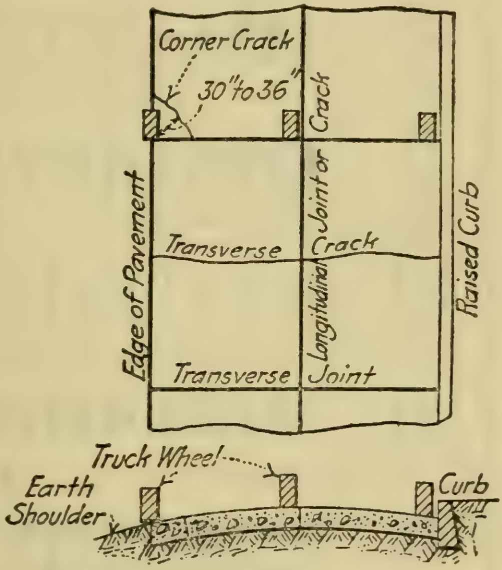


FIG. 136.—Location of critical wheel loads at internal and external corners.

Distribution of Wheel Loads at Joints.—The distribution of load between adjacent slabs at joints and cracks is a variable and indefinite factor. In monolithic pavements it depends largely on the degree of contact, which is much better during the day than at night, and better in the summer than in the winter. The use of steel-tie members in concrete increases the contact, at least temporarily (see p. 471). For pavements with separate concrete bases and top surfacing courses, like asphaltic concrete, semi-monolithic brick, etc., it is certain that the distribution of load over base cracks is much better than for the monolithic-slab type. Most of the experimental data deal with distribution at joints in monolithic concrete and brick These types will be given first consideration and the values adopted can then be modified for the other types by data which compare this factor in an indirect manner.

Monolithic-slab Joint Distribution.—Table 80, taken from an article by H. F. Clemmer, of the Illinois Department of Highways, and C. A. Hogentogler, U. S. Bureau of Public Roads, contains

TABLE 80.—OBSERVED AND COMPUTED DEFLECTIONS OF SLAB CORNERS ADJACENT TO JOINTS

Section			October night observed deflection				October day observed deflection			
No.	Thickness, inches	Kind	Load on near side	Load on far side	Per cent load carried across joint	Total movement of corners	Load on near side	Load on far side	Per cent load carried across joint	Total movement of corners
40	9	Conc.	0.081	0.024	13.0	.....	0.040	0.019	35.0	
40	9	Conc.	0.066	0.012	26.0	0.111	0.042	0.021	30.0	0.042
40	9	Conc.	0.041	0.040	49.0	.....	0.035	0.035	50.0	
39	8	Mono.	0.040	0.039	49.0	0.002	0.035	0.035	50.0	0.0
42	8	Conc.	0.078	0.037	43.0	.....	0.030	0.030	50.0	
43	7	Conc.	0.050	0.030	26.0	0.061	0.030	0.030	50.0	0.0
63B	7	Conc.	0.075	0.026	15.0	.....	0.055	0.026	18.0	
63A	7	Conc.	0.070	0.015	29.0	0.104	0.047	0.014	38.0	0.062
44	7	Conc.	0.094	0.004	11.0	.....	0.060	0.011	18.0	
45	6	Conc.	0.106	0.009	5.0	0.187	0.076	0.016	15.0	0.109
38	7	Mono.	0.045	0.045	50.0	.....	0.037	0.037	50.0	
37	6	Mono.	0.045	0.045	50.0	0.00	0.037	0.037	50.0	0.00
48	6	Conc.	0.085	0.035	47.0	.....	0.048	0.043	41.0	
47	6	Conc.	0.092	0.060	20.0	0.082	0.044	0.038	46.0	0.011
51	6	Conc.	0.114	0.095	20.0	.....	0.076	0.059	28.0	
50	6	Conc.	0.105	0.063	33.0	0.061	0.079	0.050	44.0	0.046
52	6	Conc.	0.094	0.053	15.0	.....	0.086	0.050	49.0	
51	6	Conc.	0.101	0.027	46.0	0.115	0.073	0.008	46.0	0.101

TABLE 90.—(*Continued*)

Section			Including per cent distribution day and night	December total movement day and night	Computed equal deflections for both slabs at joint					
					Rear wheel			Front wheel		
No.	Thickness, inches	Kind			Night	Day	Difference	Night	Day	Difference
40	9	Conc.	22.0							
40	9	Conc.	4.0	0.069	0.046	0.031	0.015	0.016	0.008	0.008
40	9	Conc.	1.0							
39	8	Mono.	1.0	0.002	0.040	0.035	0.005	0.009	0.006	0.003
42	8	Conc.	7.0							
43	7	Conc.	24.0	0.061	0.047	0.030	0.017	0.011	0.007	0.004
63B	7	Conc.	3.0							
63A	7	Conc.	9.0	0.042	0.046	0.038	0.008	0.016	0.008	0.008
44	7	Conc.	7.0							
45	6	Conc.	10.0	0.079	0.057	0.040	0.017	0.016	0.007	0.009
38	7	Mono.	0.0							
37	6	Mono.	0.0	0.00	0.045	0.037	0.008	0.012	0.008	0.004
48	6	Conc.	6.0							
47	6	Conc.	26.0	0.071	0.070	0.044	0.026	0.025	0.011	0.014
51	6	Conc.	8.0							
50	6	Conc.	11.0	0.015	0.098	0.066	0.432	0.028	0.018	0.010
52	6	Conc.	35.0							
51	6	Conc.	0.0	0.012	0.078	0.057	0.031	0.024	0.015	0.009

NOTE.—Equal deflections of both corners at joints indicates perfect contact, or 50 per cent distribution.

probably as reliable data as can be obtained at present (1922). This table shows a wide range in values.

It is possible that under favorable conditions the load may be equally distributed between adjacent slabs, but this is not likely to be the case for many cases at cracks in the plain concrete-slab type or at expansion joints filled with bitumen. For the most adverse conditions of contact, a single corner may carry the entire wheel load. At expansion joints it is not unlikely that this condition occurs at intervals, but as the factor of safety of the formula is to be provided by the soil-contact factor, it is not advisable to assume the highest possible value for J. Values are derived as follows for plain concrete pavements:

As defined on page 395, $J = 3 \times$ the effective part of the wheel load actually applied at the extreme corner. The effective part is made up of the part of wheel load W carried by a single corner modified for location of this load. The extreme possible range for exterior corners ranges from $1.0W$ to $0.5W$ applied at the extreme point. This would give a possible range of value for J at exterior corners as shown in the following tabulation.

Wheel load carried by single corner	Value of J (exterior corners)
$0.5W$	1.5
$0.6W$	1.8
$0.7W$	2.1
$0.8W$	2.4
$0.9W$	2.7
$1.0W$	3.0

The value of 2.6 is considered safe and reasonable for exterior-corner condition in plain concrete-slab design. Interior-corner value is reduced 15%, giving a value of 2.2 recommended.

In pavements containing imbedded steel the distribution at expansion joints is the same as for the plain concrete type. Where joints or cracks not subject to expansion movement are held in contact by tie bars or dowels, the distribution is materially increased. Some designers advocate values for J based on a 50% distribution, but this seems rather optimistic. A value for exterior corners is recommended based on $0.7W$, which equals 2.1 reduced to 1.7 for interior corners.

The adoption of values for J as applied to two-course pavements, such as asphaltic concrete, block pavements, etc., depends on indirect comparison of the action of these pavements with the monolithic type under traffic and experimental beam tests. These values for two-course pavements are still in the speculative stage, but if they are adjusted to produce rational results in conjunction with the values for W and S which are fairly certain, there is some justification for the use of the corner-load formula in connection with the design of two-course pavements.

Any top course adds something to the resistance of the concrete base by its effect on wheel impact, increase in the reliability of load distribution over base cracks, reduction in probability of load being applied at the extreme corner of the base slab, and reduction in probability of surface-water seepage through cracks to the underlying subgrade. Of these considerations, J is affected only by distribution and location of load.

The recommended values are based on the consensus of opinion of engineers in western New York and on experimental results of the Bates Road Tests and the following quotation from an article by C. A. Hogentogler, U.S. Bureau of Public Roads, November, 1921, summarizing recent Arlington experimental tests:

"The monolithic brick-concrete slabs in most cases showed less resistance than the 1:1½:3 concrete slabs of the same depth. Failure of the former seemed to result from the shearing of the brick top from the concrete base before full resistance of the monolithic was developed. This allowed the specimens to develop at most only the sum of the resistance of the two parts. The monolithic sections tested as beams under static loads failed in the same way, but the resistance of the beams seemed to be slightly in excess of the sum of the top and bottom strengths, while the slab resistances compared favorably with the sum of the resistances of the two parts. This would indicate that higher shearing stresses are developed by impact than by equivalent static loads.

"With possibly one exception (slab 106), the grouted-brick tops with sand-cement cushions or concrete bases showed less resistance than the monolithic sections.

"Grout-filled brick tops with sand and screening cushions on concrete bases showed slightly greater resistance than would be expected from the bases alone.

"Grout-brick surfaces compared favorably with 1:1½:3 slabs of equal thickness, while grouted-brick beams showed resistances in excess of those offered by equal thicknesses of 1:1½:3 concrete.

"As would be expected, the beam strengths of the bases were not much increased by bitumen-filled brick to brick tops."

TABLE 81.—RECOMMENDED VALUES J TWO-COURSE PAVEMENTS

Type of pavement	Value of J, interior-corner classification
Asphaltic-concrete pavements	1.2–1.3
Block pavements (bituminous joints)	1.2–1.3
Block pavements (cement-grout joints)	0.8–0.9

RECOMMENDED VALUES J MONOLITHIC PAVEMENTS

Type of pavement	Value J, exterior corners	Value J, interior corners
Plain concrete	2.6	2.2
Monolithic brick	2.6	2.2
Reinforced concrete		
At expansion joints	2.6	2.2
At cracks or contraction joints with bar ties	2.1	1.7

Soil Support (Percentage Modification Factor P).—As this is the most indefinite element of the problem, it seems desirable to adopt values which are on the safe side and in this way provide the necessary factor of safety for the formula. The depths directly computed by the formula $d = \sqrt{\frac{JW}{S}}$ assume complete loss of soil support. If soil support is given some consideration in design, it is recognized by an arbitrary percentage modification of depths and the percentage used must agree with the observed action of pavements under traffic tests on different subsoils. For practical application to design the formula may be written as

$$d = P\sqrt{\frac{JW}{S}},$$ where P represents the soil-support factor.

Engineers differ considerably in regard to the allowable reduction in depth due to partial soil support; they are, however, practically unanimous in agreement that some allowance should be made for the factor, particularly where a rigid pavement is laid on top of an old, firm macadam road in reconstruction programs. Where really unstable subgrades, such as muck or quicksand, are encountered, it is necessary to stabilize the subgrade by means of gravel or cinder subbase well underdrained before the rigid pavement can be laid with any degree of success. The value assigned to P has an important effect on the practical value of the formula.

If the complete loss of soil support were a common continuous occurrence on the ordinary subgrade soils, such as loams and the stiffer clays, there would be a larger percentage of failure on some of the old thin rigid pavements than has actually been the case. This indicates that these soils usually give some support. On the other hand, there have been enough observed failures to indicate that it is not safe to assume much support from these soils under adverse conditions. The following short quotation from *Bulletin* 18, "Bates Experimental Road," gives experimental data in connection with the loss of soil support due to temperature warping.

"The curling of the edges of a concrete slab 18′ wide may be sufficient to render the most perfect of subgrades ineffective under the edges of the slab. This can be readily determined without the aid of accurate measuring devices. To visualize this condition the line drawings shown on page 411 which are based on photographs were made.

Best available data indicate that monolithic pavements having slab widths of 10′ or less and the usual two-course pavements having widths of 20′ or less generally receive some benefit from support at edges and corners. Experience indicates that if we adopt values for P of 1.1 for wide monolithic slabs and values of 0.8 to 1.0 for narrow slabs and two-course pavements the results are safe. The following values for P depending on the character of the subgrade seem to be about as good a guess as can be hazarded at present (1923).

TABLE 82.—RECOMMENDED VALUES (P) (SOIL-SUPPORT FACTOR)

Subgrade conditions	Type of pavement	Adopted formula
Ordinary loams and clays.	Wide monolithic slabs	$d = 1.1\sqrt{\frac{JW}{S}}$
	Narrow slabs or two-course pavements	$d = 1.0\sqrt{\frac{JW}{S}}$
Coarse gravels or macadams.	Wide monolithic	$d = 1.0\sqrt{\frac{JW}{S}}$
	Narrow slabs or two-course pavements	$d = 0.9\sqrt{\frac{JW}{S}}$
Quicksand and muck	Wide monolithic	Subbase $+ d = 1.1\sqrt{\frac{JW}{S}}$
	Narrow monolithic or two-course pavements	Subbase $+ d = 1.0\sqrt{\frac{JW}{S}}$

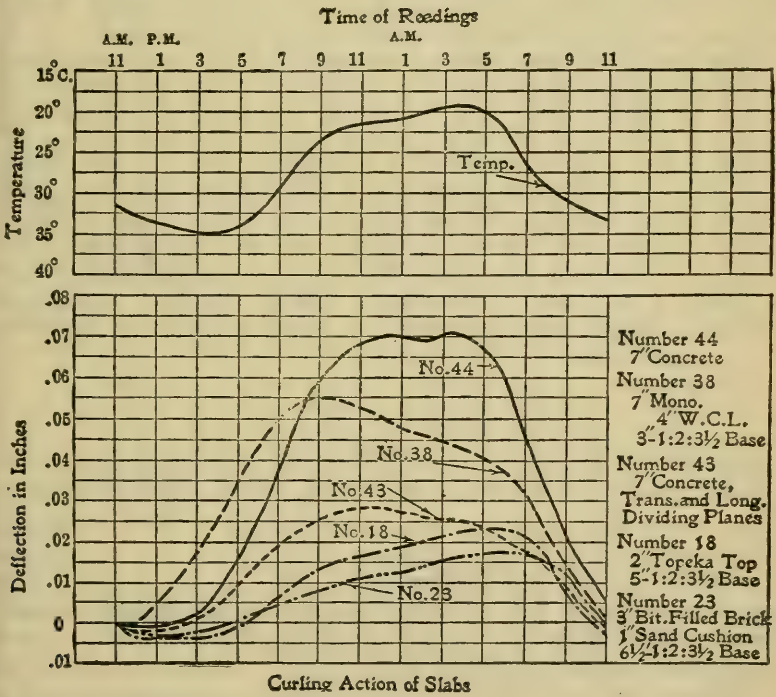


FIG. 137.—Bates road experiments on rigid slab warping due to temperature.

Summary of Discussion of Factors.—The preceding discussion outlines the wide range of possible values for each of the factors in the formula $d = P\sqrt{\frac{JW}{S}}$. There is enough variation in these

values to give some theoretical justification for practically any depth in common use. The range in values shows that proper design depends very largely on the judgment of the designer. The student may well bear in mind, however, that many engineering formulas, such as sewer run-off, etc., which have been found very useful in practice, are susceptible to the same variation in final results and that the values of such formulas have been gradually increased by modifying experimental factor values to agree with actual service tests. A formula of this nature is very useful in coordinating the experience of a large number of different men working on the same general problem, as it affords a convenient means of expressing their experience in mathematical form.

The practical use of the corner-load formula is illustrated in the following pages for each common type by showing the range in possible values, giving a recommended set of values for normal conditions and computing the depths required for different wheel-load limits. These results are compared with ordinary practice. It is not likely that the recommended depths can be safely changed more than 5 to 10% for normal conditions. For special traffic conditions changes can be made in the factor values, but it is not desirable to use a combination of all high or all low values.

Plain Concrete Pavements.—Pages 449 to 474 give a discussion of joint details, richness of mix, etc. Design is based, as a rule, on a system of longitudinal and transverse joints which divide the pavement into slabs of from 8 to 12′ width and from 30 to 40′ length, which usually control the natural tendency of the pavement to crack under temperature and frost action. That is, some intermediate cracking will occur, but the intersection of joints and the infrequent internal cracking are at approximately 90° angles. Richness of mix varies from 1:2:4 on unimportant roads to 1:1½:3 on main heavy-traffic roads. Factor values and resultant depths are indicated as follows for the formula $d = P\sqrt{\frac{JW}{S}}$:

Recommended Factor Values for Roads of Classes I and II in Districts Permitting a 28,000-lb. Gross Vehicle Road

Design wheel load, including impact W, pounds..........	14,000
Load distribution J, exterior corners....................	2.6
Load distribution J, interior corners....................	2.2
Design tensile stress S, 1:1½:3 mix, pounds per square inch	400
Design tensile stress S, 1:2:4 mix, pounds per square inch	360
Soil-support factor P, ordinary soils....................	1.0
Soil-support factor P, gravel and macadam..............	0.9

These values result in the following recommended theoretical depths for 1:1½:3 mix (28,000-lb. vehicle load).

Ordinary foundation soils:

$$\text{Outer edge of pavement } d = 1.0\sqrt{\frac{2.6(14{,}000)}{400}} = 9.5''$$

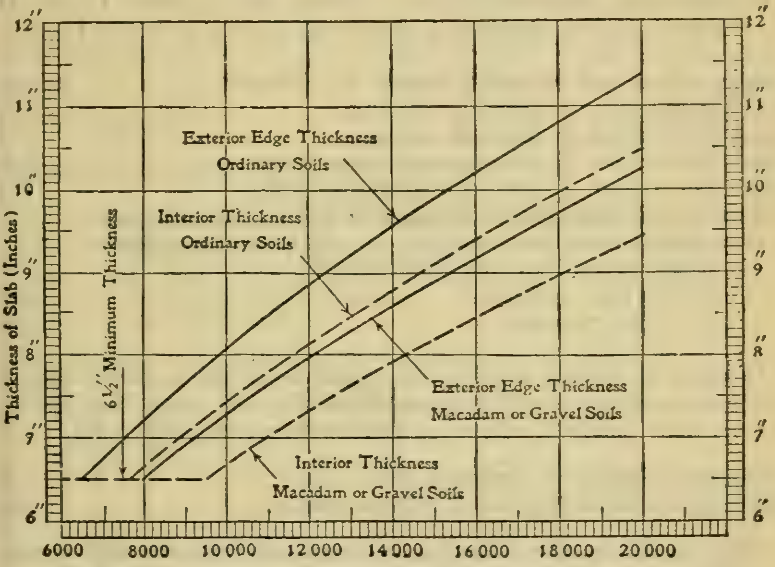
Interior areas[1] of pavement $d = 1.0\sqrt{\frac{2.2(14,000)}{4}} = 8.8''$

Gravel or macadam foundation:

Outer edge of pavement $d = 0.9\sqrt{\frac{2.6(14,000)}{400}} = 8.5''$

Interior areas[1] of pavement $d = 0.9\sqrt{\frac{2.2(14,000)}{4}} = 7.9''$

Variations in depth due to changes in the design wheel load are shown in Fig. 138 below.



Design Wheel Load in lbs. (Includes Impact Allowance)

3½ ton truck (16,000 lbs. gross load) Design Wheel load 9500 lbs.
5 ton truck (22,000 lbs. gross load) Design Wheel load 11,500 lbs.
7 ton truck (28,000 lbs. gross load) Design Wheel load 14,000 lbs.

FIG. 138.—Theoretical thickness plain concrete slabs 8 to 12 ft. wide 1:1½:3 mix (crushing strength 28-day age 3000 to 4000 lb. per square inch).

Ordinary practice in plain concrete road design uses average depths of from 5½ to 11″ (see Table 84, p. 417).

Where pavements are constructed over new trenches (culverts or sewers) which will surely settle, the slab depths at such localized places are designed on the principle of bridge slab depths with extra bottom reinforcement (see p. 417).

While a considerable mileage of plain concrete pavements has been constructed and is serving moderately well, the tendency is to use some steel, as considered in the next section.

Reinforced-concrete Pavements.—These pavements are designed on the same general arrangement of joints as the plain concrete

[1] Interior-area classification applies to total width of curbed streets.

except that the length of the slab is usually somewhat greater (40′ being a common length).[1] The following theoretical depths consider steel 100% effective for tie purposes but of little effect in increasing tensile strength for slabs less than 6½″ thick. The depth of the pavement is computed on the basis of corners at intermediate cracks between expansion joints where good contact is fairly certain. Corners at expansion joints are given the same thickness as close contact corners and the necessary additional bar reinforcement is provided to take care of the extra stress due to poorer joint distribution.

RECOMMENDED FACTOR VALUES. ROADS OF CLASSES I AND II IN DISTRICTS PERMITTING A 28,000-LB. GROSS VEHICLE LOAD

Design wheel load including impact W, pounds	14,000
Load distribution J, exterior corners	2.1
Load distribution J, interior corners	1.7
Load distribution J, exterior expansion joints	2.6
Load distribution J, interior expansion joints	2.2
Design tensile strength for all parts of slab except at expansion joint corners, assuming 0.3- to 0.4-lb. mesh reinforcement per square foot and side tie bars:	
1:1½:3 mix, pounds	450
1:2:4 mix, pounds	420

If mesh is omitted and tie bars alone used, the tension value S is recommended at 400 lb. per square inch (1:1½:3 mix) and 360 lb. (1:2:4 mix), using J values for tight contact (see Fig. 140).

Soil-support factor P, ordinary soils	1.0
Soil-support factor P, gravel or macadam	0.9

This results in the following recommended depths and corner reinforcement for 1:1½:3 mix (28,000-lb. gross vehicle load).

Ordinary foundation soils:

$$\text{Outer edge of pavement } d = 1.0\sqrt{\frac{2.1(14{,}000)}{450}} = 8.1''$$

$$\text{Interior areas}^2 \text{ of pavement } d = 1.0\sqrt{\frac{1.7(14{,}000)}{450}} = 7.3''$$

Design tensile stress at expansion joint corners:

$$\text{Outside corner } S = \frac{JW}{d^2} = \frac{2.6(14{,}000)}{8.1^2} = 550 \text{ lb.}$$

$$\text{Inside corner} = \frac{2.2(14{,}000)}{7.3^2} = 580 \text{ lb.}$$

[1] On account of future surfacings of bituminous concrete 33′ is probably a better spacing to reduce localized movement.
[2] Interior-area classification applies to total width of curbed streets. Design tensile stress at expansion-joint corners.

Figure 135 (p. 401) indicates that a design stress of 580 lb. requires approximately 0.3 to 1% area of reinforcement. This applies for the sectional area of the slab back about 30″ from the extreme corner. Size and spacing of corner bars are based on these data.

Gravel or macadam foundation:

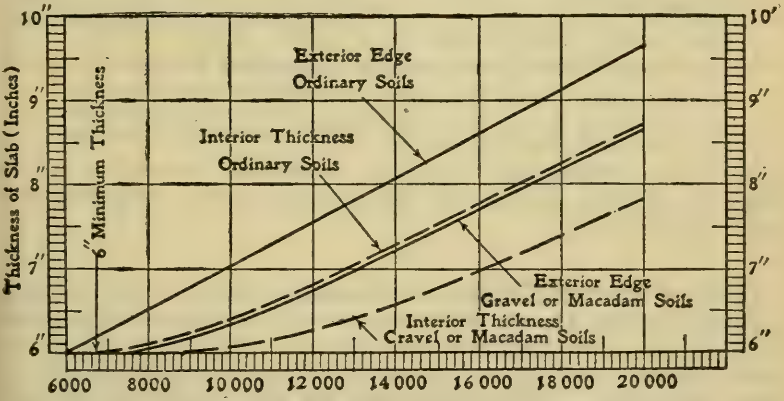
$$\text{Outer edge of pavement } d = 0.9\sqrt{\frac{2.1(14{,}000)}{450}} = 7.3''$$

$$\text{Interior areas[1] of pavement } d = 0.9\sqrt{\frac{1.7(14{,}000)}{450}} = 6.6''$$

$$\left.\begin{array}{ll}\text{Outside corners } S = 0.8\dfrac{JW}{d^2} = 0.8\dfrac{2.6(14{,}000)}{7.3^2} = 550 \text{ lb.} \\ \text{Interior corners} \qquad = 0.8\dfrac{2.2(14{,}000)}{6.6^2} = 570 \text{ lb.}\end{array}\right\}\text{Expansion joints.}$$

Requires three-tenths of 1% reinforcement.

Concrete 1:1½:3 Mix Crushing Strength (28 days) 3000 to 4000 lbs.
Reinforcement—Mesh and Bar.
Mesh 0.3 to 0.4 lbs. per sq. ft.
Total Corner Steel 0.3 of one % Section area for 30″ from Corner
Side Tie bars (See page 451)
Central Longitudinal Joint.



Design Wheel Load in lbs. (Include Impact Allowance)

3½ ton truck (16,000 lbs. gross load) Design Wheel load 9,500 lbs.
5 ton truck (22,000 lbs. gross load) Design Wheel load 11,500 lbs.
7 ton truck (28,000 lbs. gross load) Design Wheel load 14,000 lbs.

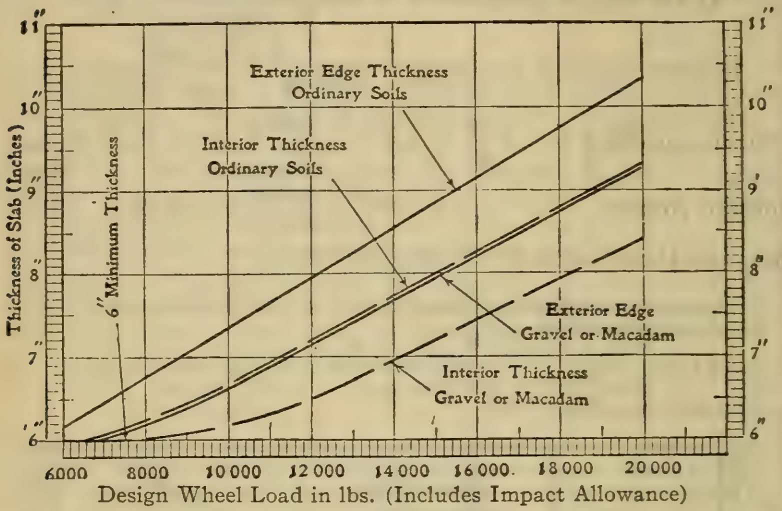
Note: The difference in the general shape of this curve from the plain Concrete curve is due to the decreasing effectiveness of steel for slabs less than 7″ thick

Fig. 139.—Theoretical thickness reinforced cement concrete. 1:1½:3 mix, mesh and bar reinforcement, transverse and longitudinal joints.

[1] Interior-area classification applies to total width of curbed streets. Design tensile stress at expansion-joint corners.

Theoretical variation in depth due to changes in the design wheel load are shown in Figs. 139 and 140 for 1 : 1½ : 3 mix with different kinds of reinforcement.

Concrete 1 : 1½ : 3 Mix Crushing Strength (28 days) 3000 to 4000 lbs.
Reinforcement Side Tie Bars (See page 453)
Corner Bar Reinforcement 0.3 of one % Section
Area for 30″ back from Corner
Central Longitudinal Joint.



3½ ton truck (16,000 lbs. gross) Design Wheel load 9,500 lbs.
5 ton truck (22,000 lbs. gross) Design Wheel load 11,500 lbs.
7 ton truck (28,000 lbs. gross) Design Wheel load 14,000 lbs.

FIG. 140.—Theoretical thickness reinforced concrete 1 : 1½ : 3 mix, side tie bar and corner bar reinforcement, transverse and longitudinal joints.

Effect of Steel on Depth.—A comparison of Figs. 138, 139, and 140 indicates that the use of tie and corner bars reduces the required thickness of plain concrete slabs about 1″ and that the use of mesh, tie bars, and corner bars reduces the required depth of concrete about 1½″. This applies only for load conditions requiring depths of plain concrete of 8″ or more. Expressed in terms of money, tie and corner bars reduce the cost of concrete about 4 cts. a square foot (1922 cost conditions) and tie, corner bars, and mesh reduce the cost of the concrete about 6 cts. per square foot. The cost of the steel used as reinforcement should not exceed these limits. The cost of steel reinforcement is usually less than this amount, which indicates that the use of steel is economically desirable.

Ordinary practice in reinforced-concrete-pavement design uses average depths of from 5 to 8″. For relative depths of sides and edges and reinforcement details see page 455.

Depths over Trenches.—Where pavements are constructed over new trenches (culverts or sewers) which will surely settle, the slab

depths at such localized places should be thickened and given additional bottom reinforcement to conform with bridge-floor slab practice. The following table indicates in a general way the maximum width of trench it is safe to span with standard road slabs of 1 : 1½ : 3 mix for different legal load limits based on formula (safe span) $= \frac{32S(d)^2}{W}$:

TABLE 83.—TRENCH WIDTHS REQUIRING ADDITIONAL STRENGTH

Maximum load	Approximate maximum allowable trench width safe to span without additional thickening (1: 1½: 3 mix), in feet. Column headings are depths of standard pavement slabs			
	6″	7″	8″	9″
3½-ton truck (16,000 lb. gross)	4.0′	5.5′	7.5′	9.5′
5-ton truck (22,000 lb. gross)	3.5′	5.0′	6.5′	8.0′
7-ton truck (28,000 lb. gross)	3.0′	4.5′	5.5′	6.5′

NOTE.—These widths assume beam action, that is, joints must not be constructed directly over a trench.

TABLE 84.—TABLE OF RANGE IN DEPTH OF CONCRETE PAVEMENTS. CURRENT PRACTICE, 1919–1922, IN INCHES

State	Plain concrete	Reinforced concrete
Arizona	5½ – 9	....
California	6	5 – 6
Connecticut	6 – 9	....
Illinois	....	6 – 9
Indiana	7 – 8	7 – 8
Maryland	6½ – 8	....
Massachusetts	....	7½ – 8
Minnesota	....	7½
New Jersey (1922)	8	8
New Jersey (1919)	6 – 10½	....
New York	....	6 – 7
Pennsylvania	7 – 9	6 – 8
Rhode Island	6 – 8	6 – 8
Washington[a]	6 – 11[a]	6 – 11[a]
West Virginia	6 – 9	....
Wisconsin	7 – 8	....

[a] State of Washington, 11″ depth for short distances where settlement may occur.

NOTE.—The preceding theoretical analysis indicated the following depths as reasonable for a 28,000-lb. gross vehicle load, ordinary foundation soils:

Plain concrete (1: 1½: 3 mix) .... 8¾–9¾″
Reinforced concrete (1: 1½: 3 mix) .... 7½–8½″

Trend in Design.—A comparison of Table 84 on current practice depths with the preceding discussion of recommended theoretical depths shows that, with the exception of a few of the states, the maximum thickness in common use is somewhat less than the theoretical depths developed for a 28,000-lb. gross vehicle limit.

These theoretical depths are based on the maximum statutory load adopted in a number of the thickly settled states, as it is believed that loading on main roads will tend to increase to the limit permitted by law. As previously discussed, the rigid type of pavement is rarely economical on moderate or light-traffic roads, so the theoretical depths have been developed to represent Class I traffic requirements. The states using depths as developed by these formulas are generally thickly settled with large cities and a heavy volume of commercial trucking on the main intercity routes. It is believed that a rigid pavement is not usually justified unless such conditions prevail, but a great many localities are building lighter concrete roads for lighter traffic. If the designer is willing to recognize that he is taking a chance and considers the concrete pavement as a temporary expedient with the idea of capping it in a short time with some standard renewable surface, it may be justifiable to reduce the depth to that required for two-course pavement bases. Under this line of reasoning the following minimum depths have some justification, on the basis that the proposed future surfacing will raise the strength of the finally completed pavement up to that required for a 28,000-lb. gross vehicle load.

Plain concrete:

1:1½:3 mix	6½″
1:2:4 mix	7 ″

Reinforced concrete:

1:1½:3 mix	6 ″
1:2:4 mix	6½″

It, however, seems undesirable to carry this idea too far, as it tends to discredit this type of pavement, which is very useful and economical if properly designed for roads carrying from 2000 to 6000 vehicles daily.

Bituminous-Concrete Surface on Cement-Concrete Base.—Cement-concrete bases for these pavements are usually constructed as a continuous slab without any special provision for expansion or contraction. These bases crack with more or less regularity transversely across the pavement at intervals of 30 to 60′, and more infrequently in a longitudinal line near the center of the pavement and roughly parallel with the edges; that is, the action of the elements combined with traffic produces a series of slabs of varying sizes and shapes. Cracks in the asphaltic-concrete surface often develop directly over the base crack, but do not always show through to the surface, which depends largely on the width of the base crack. Wide base cracks are not so frequent for the lean concretes as for the rich concretes because the coefficient of expansion is considerably less for a 1:3:6 than it is for a 1:2:4 mix (see

THE TREND OF CONCRETE PAVEMENT DESIGN BY YEARS FROM HIGHWAY RESEARCH NEWS, AUGUST, 1926

(Tabulation by U. S. Bureau of Public Roads. Based on Federal-Aid Prospects)

Pavement thickness (inches)			Number of projects submitted by the 48 states by years								
Edge	Center	Edge	1917	1918	1919	1920	1921	1922	1923	1924	1925
5	5	5	....	1	....	1	2	1	....	....	....
6	6	6	2	3	3	24	24	49	10	4	3
7	7	7	1	11	17	31	22	80	70	33	47
7½	7½	7½	2	4	17	31	21	30	9	1	....
8	8	8	4	17	68	90	78	85	61	51	44
9	9	9	....	1	13	9	9	8	8	....	....
10	10	10	....	....	5	5	5	2	2	....	1
12	12	12	....	....	....	....	....	....	2	....	1
5	6	5	....	....	1	11	3	1	....	....	....
5	7	5	4	10	7	4	....	3	....	....	....
6	7	6	....	1	9	17	8	39	25	....	....
6	8	6	4	13	92	60	56	71	16	25	9
7	8	7	1	11	65	55	23	24	18	....	....
7	9	7	....	....	1	2	....	2	4	....	....
8	10	8	....	....	....	....	....	1	1	....	....
7	5	7	....	....	....	....	....	1	....	....	....
7	6	7	....	....	....	....	....	1	23	38	43
7½	5½	7½	....	....	....	....	....	....	....	....	15
7½	6	7½	....	....	....	....	....	....	....	12	....
8	5	8	....	....	....	....	....	....	....	4	....
8	6	8	....	....	....	....	1	8	17	21	72
8	6½	8	....	....	....	....	....	....	....	....	4
8	7	8	....	....	....	....	....	....	3	25	33
9	5	9	....	....	....	....	....	....	....	2	1
9	6	9	....	....	....	....	3	....	55	180	160
9	6½	9	....	....	....	....	....	....	....	22	34
9	7	9	....	....	....	....	....	9	6	38	49
10	7	10	....	....	....	....	....	2	1	5	3
10	8	10	....	....	....	....	....	1	3	9	3
12	6	12	....	....	....	....	....	....	....	....	1
Total thin edge or uniform			18	72	298	340	251	396	126	114	105
Total thickened edge.....			0	0	0	0	4	122	108	356	418

Chap. XIV, p. 1053) and the lean bases generally develop transverse cracks at shorter intervals due to less tensile strength. On account of this tendency of rich mixes to aggravate surface cracks in the overlying asphaltic surfaces most engineers advocate a base mix of from 1:3:5 to 1:2½:5, either one of which is a good practical mix as regards requisite resistance to moisture absorption and practical construction manipulation.

Pavements of this type on rural highways are generally constructed with an integral concrete edging to hold the edge of the mix from side displacement. The extra depth of concrete along the edge is usually considered to give the necessary extra strength of edge as compared with interior-corner conditions; that is, the base depth is made uniform and based on the interior-corner

classification where integral concrete edging is used. Where no edging is used the outer edge should be strengthened by any simple method, either extra edge depth or raised curbing.

In designing base depth for this type of pavement it is not permissible to figure on future strengthening. Adequate base strength must be provided as future renewals of worn-out asphaltic concrete surfaces remove the old surface course and replace with fresh mix; that is, resurfacing adds nothing to the final strength of this type of pavement.

The asphaltic surface wearing course varies, as a rule, from 2″ without a binder course to 3″, including a binder course. These depths are the result of experience and represent what appear to be feasible depths, considering construction and maintenance problems. The variation in depth of asphalt surfaces as between 2 or 3″ has little effect on the pavement base depth.

Recommended Factor Values for Roads of Classes I and II in Districts Permitting a 28,000-lb. Gross Vehicle Road

Design wheel load, including impact W, pounds	12,000
Load distribution factor J, interior corners	1.3
Design tensile stress, plain concrete base:	
1:3:6 mix, pounds	280 per square inch
1:2½:5 mix, pounds	320 per square inch
1:2:4 mix, pounds	360 per square inch
Soil-support factor P, ordinary soils	1.0
Soil-support factor P, gravel and macadam	0.9

These values result in the following recommended base depths for 28,000-lb. gross vehicle load. See Fig. 141 for more complete graphic results for different mixes and different design loads.

Ordinary foundation soils:

1:2½:5 mix

$$\text{Depth of base } d = 1.0\sqrt{\frac{1.3(12{,}000)}{320}} = 7''$$

Gravel and macadam subsoils:

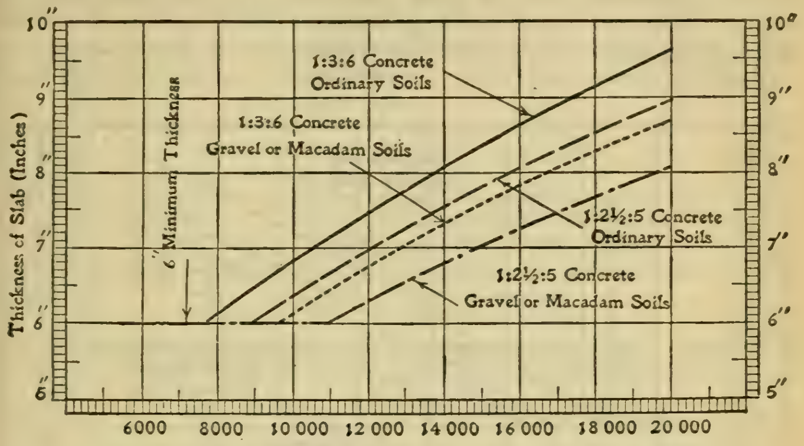
$$\text{Depth of base } d = 0.9\sqrt{\frac{1.3(12{,}000)}{320}} = 6.3''$$

A few examples of ordinary practice in base depths are given as follows. Table 85 (p. 424) shows recent city-street practice on heavy-traffic streets.

Illinois (rural highways)	7″ (1:2 :3½ mix)
Pennsylvania (rural highways)	6″ (1:2½:5 mix)
New Jersey (rural highways)	6″ (1:3 :5 mix)
New York (rural highways)	5″ (1:2½:5 mix)
New York City (business streets)	9″ (1:2½:5 mix)

Depth over Trenches.—Increase in base depth applies as discussed on page 416. For 7-ton truck loading it is probably desirable to

increase for a 6″ standard base of 1:3:6 concrete for trenches over 3′ wide, for a 7″ depth of base where the trench width exceeds about 3.5 to 4′.



Design Wheel Load in lbs. (Includes Impact Allowance)

3½ ton truck (16,000 lbs. gross load) Design Wheel load 8500 lbs.
5 ton truck (22,000 lbs. gross load) Design Wheel load 10,000 lbs.
7 ton truck (28,000 lbs. gross load) Design Wheel load 12,000 lbs.

General Formula $d = P\sqrt{\frac{1.3W}{S}}$

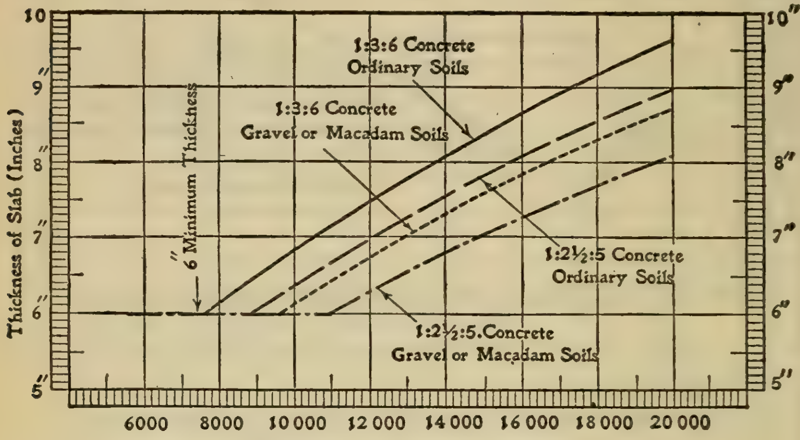
FIG. 141.—Theoretical depth of cement concrete bases under bituminous concrete surfaces.

Brick, Stone Block, etc., with Mastic Filler on Sand or Cement-sand Cushion and Concrete Base.—This design is rarely used on rural roads, as it is expensive. The advantage of the mastic filler lies in the prevention of surface cracks. The prevention of these cracks on the score of better appearance of the pavement is important in cities, but of secondary importance on rural highways. The disadvantage of the mastic filler lies in the loss of cantilever beam strength in the surface course and the production of more impact as the road serves traffic. It is not likely that the increase in impact is balanced by the cushion depth under the brick. It is certain that the base cannot be reduced in thickness below that required for sheet asphalt and the probabilities are that a slight increase is logical. Formula, $d = \sqrt{\frac{1.3W}{S}}$, with the additional impact allowance (see p. 404), seems to be about as good a guess as can be made on the basis of comparative action under traffic tests. This is perhaps a little ultraconservative.

For depths in use, see Tables 85 (p. 424) and 86 (p. 426). Figure 142 illustrates graphically the results obtained by applying this formula.

Grouted Brick, Stone Block, etc., on Cement-sand Cushion and Concrete Base.—These types have the advantage of considerable

beam strength in the surface layer as well as the base beam strength; according to the Office of Public Roads tests previously quoted, they apparently do not, as a rule, develop as much beam strength as the monolithic form of brick pavement, but the difference is slight. The evidence of actual pavements indicates that they give satisfactory service with bases somewhat less in depth than the asphaltic concrete-top type. Personally, the author believes that



Design Wheel Load in lbs. (Include Impact Allowance)

3½ ton truck (16,000 lbs. gross load) Design Wheel load 10,000 lbs.
5 ton truck (22,000 lbs. gross load) Design Wheel load 12,500 lbs.
7 ton truck (28,000 lbs. gross load) Design Wheel load 15,000 lbs.

General Formula $d = P\sqrt{\frac{1.3W}{S}}$

FIG. 142.—Theoretical depth of cement concrete base under brick surface (mastic filler cement sand cushion).

the semimonolithic type will work satisfactorily under a design based on the depth of base $= \sqrt{\frac{0.9W}{S}}$; this is a rational modification of the asphaltic-type formula, as the grouted surface slab certainly adds more strength to the pavement than an asphaltic top and by beam action gives a wider distribution of load over base cracks and corners. As these formulas are intended to give relatively correct results, and as experimental results are meager, this form will be tentatively adopted. Thus the application of the corner load formula to this type is a speculative proposition.

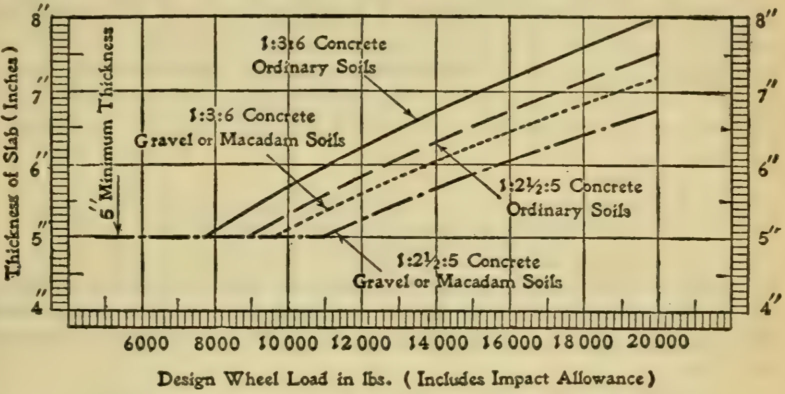
The base under this formula becomes for loam and clay soils (28,000-lb. gross vehicle load):

$$1:2:4 \text{ mix } \sqrt{\frac{12,600}{360}} = 6''$$

$$1:2\tfrac{1}{2}:5 \text{ mix } \sqrt{\frac{12,600}{320}} = 6.3''$$

$$1:3:6 \text{ mix } \sqrt{\frac{12,600}{275}} = 6.8''$$

On gravel or old macadam subsoils the depths can be safely reduced ½ to ¾″, but should under no circumstances of either load or soil be reduced below a 5″ minimum. Figure 143 illustrates graphically the results of applying this formula.



8½ ton truck (16 000 lbs. gross load) Design Wheel load 9500 lbs.
6 " " (22 000 " " ") " " " 11 500 "
7 " " (28 000 " " ") " " " 14 000 "

General Formula $d = P\sqrt{\frac{0.9W}{S}}$

FIG. 143.—Theoretical depth of cement concrete bases under 4-in. brick surface (cement grout joints, cement sand cushion).

Monolithic-brick-pavement Slabs.—This type has the same general characteristics as the monolithic plain concrete as far as impact and load distribution at cracks are concerned. The difference between these two types lies in the fact that the plain concrete pavement is a true monolith and the combination of brick and concrete introduces a plane of weakness between the surface and bottom layers. The Bureau of Public Roads experiments indicated that the beam strength of the so-called monolithic-brick-pavement slabs was somewhat greater than the sum of the resisting moments of the upper and lower layers considered separately. Values of modulus of rupture for well-grouted brick surfacing slabs, as determined by the Bureau of Public Roads, range from 600 to 1000 lb. With these data, it is possible to make a speculative approximation of comparative strength depth. On page 412 the average depth of plain concrete 1 : 1½ : 3 mix using a tensile strength of 400 lb. per square inch was figured as 9.2″ for a design load of 14,000 lb.

The resisting moment of this beam per foot of width is approximately 67,000 in.-lb. It will be assumed that 75% of this must be handled by the sum of the resisting moments of the base and top considered separately, 50,000 in.-lb. Assume a working stress of 600 lb. for the brick top. A 4″ brick slab has a resisting moment per foot width of 19,200 in.-lb. This leaves 31,000 in.-lb. for the base to handle.

Expressed as a formula, the depth of concrete base = $\sqrt{\frac{1.8W - 9600}{S}}$ for loam and clay soils. On gravel or old macadam the depth can be reduced about an inch but under no circumstances of load or soil should a depth of less than 4″ be used.

Depth of top	Average depth of concrete base, inches	Total depth of pavement, inches
4″ brick top:		
1: 1½: 3 mix......	6.3	10.2
1: 2: 4............	6.7	10.6

A few examples of current practice in monolithic-brick construction follow: Monolithic-brick construction is not in much favor in the northern states on account of cracking due to frost action and slab warping. Central longitudinal joints are not generally used on this type.

	Top, inches	Base, inches	Total, inches
Illinois...............	4	(1: 2: 3½ mix)	8
Indiana..............	4	4	8

Current Practice (Two-course Pavements).—Table 85 records current practice (1922) in two-course pavement construction on heavy-traffic city streets.

TABLE 85.—CURRENT PRACTICE IN DEPTH OF CONCRETE BASE UNDER PAVEMENTS ON HEAVY-TRAFFIC CITY STREETS (1922)

City	Type of surface				Remarks
	Asphaltic concrete on concrete base, inches	Brick or stone block cement grout filler, inches	Brick or stone block mastic filler, inches	Concrete, inches	
Cleveland, Ohio....	8	6	7	....	Tendency towards 7 to 8″ except for grout-filled block.
Detroit Mich.......	8	8	8		
Chicago, Ill.........	8	8	8	....	This is recommended future practice.
Philadelphia, Pa...	6	6	6		
Indianapolis, Ind...	6	6	6	....	Gravel subsoil
Baltimore, Md......	6–8	6–8	6–8	....	8″ on poor soil.
New Orleans, La...	6	6	6		
Boston, Mass.......	6	6	6	....	Has been satisfactory.
Portland, Ore......	6	6	6	6–10	

Effect of Statutory Load Limit on Thickness of Rigid Pavements and Concrete Pavement Bases.—Table 86 gives a quick means of comparing the effect of load limit on rural pavement design. The black-faced type indicates the recommended depths for the statuatory gross vehicle limitation of 28,000 lb. which seems to be gaining favor as a practical basis of traffic regulation for the main roads. The depths given approximate equal strength for the different types and can be used as the basis for comparative estimates of cost. The determination of the effect of statuatory load and equal strength for different types are the main practical advantages of the foregoing analysis.

SPECIAL QUALIFICATIONS AND DRAWBACKS OF DIFFERENT PAVEMENTS

Limitations Imposed by Steep Grades.—The following tabulations[1] represent current practice in regard to the steepest advisable grades on which various types are satisfactory, considering safety and maintenance costs.

Surface Material	Per Cent
Wood block[1]	3
Asphalt block[1]	6
Brick[1]	10
Sheet asphalt[1]	5
Asphaltic concrete[1]	7
Bituminous macadam (seal coat)[1]	8
Bituminous macadam (no seal coat)[1]	10
Cement concrete[a]	8
Hillside brick block[1]	12
Stone block[1]	12
Wooden block[2]	2
Asphalt block[2]	4
Brick (grout joints)[2]	5
Brick (mastic joints)[2]	8
Concrete[a]	5–7
Bituminous macadam with flush or squeegee coat (in sandy country, 6% when coarse sand is sprinkled on surface)[2]	5
Bituminous macadam without squeegee[2]	8
Water-bound macadam[2]	8
Hillside brick[2]	12
Stone block with open joints[2]	12

[a] Hard to construct on grades over 5 % (special care needed).
[1] Taken from Agg's "Roads and Pavements."
[2] Taken from Harger's "Rural Highway Pavements."

On steep grades, stone block seems to be the best solution, hillside brick second, penetration one coat pour bituminous macadam third, and water-bound macadam fourth. The last two become slippery if maintained by surface oiling and it has been necessary in some cases to build a specially wide shoulder treated

TABLE 86.—SUMMARY OF RECOMMENDED THEORETICAL DEPTHS OF CEMENT-CONCRETE BASES FOR DIFFERENT PAVEMENTS UNDER DIFFERENT MAXIMUM LOADS ON DIFFERENT SOILS (IN INCHES)

(The last column gives prevailing practice in base depth for each type, 1919 to 1922.)

Pavement	Recommended depths of cement-concrete bases based on modified corner load formula $d = P\sqrt{\frac{JW}{S}}$						Current practice 1919–1923, inches
	3½-ton truck 16,000-lb. gross load		5-ton truck 22,000-lb. gross load		7-ton truck 28,000-lb. gross load		
	Ordinary subsoils, inches	Gravel or macadam, inches	Ordinary subsoils, inches	Gravel or macadam, inches	Ordinary subsoils, inches	Gravel or macadam, subsoils, inches	
Plain concrete:							
1 : 1½ : 3 mix	7.2 & 7.8	6.5 & 7.0	7.9 & 8.8	7.2 & 8.0	8.7 & 9.7	8.0 & 8.8	6–10
1 : 2 : 4 mix	7.6 & 8.2	6.9 & 7.4	8.4 & 9.2	7.6 & 8.3	9.2 & 10.0	8.4 & 9.1	
Reinforced concrete (mesh and bar): Central longitudinal joint 1 : 1½ : 3 mix	6.3 & 6.9	6.0 & 6.4	6.7 & 7.5	6.2 & 6.8	7.3 & 8.2	6.5 & 7.3	
Reinforced concrete (corner and exterior tie bars only):							
Central longitudinal joint 1 : 1½ : 3 mix	6.5 & 7.0	6.0 & 6.4	7.0 & 7.8	6.3 & 7.1	7.7 & 8.5	7.0 & 7.7	5– 9
1 : 2 : 4 mix	6.9 & 7.4	6.4 & 6.8	7.4 & 8.2	6.7 & 7.4	8.1 & 9.0	7.4 & 8.1	
Monolithic brick, 4″ brick on 1 : 1½ : 3 concrete base	4.5	4.0	5.0	4.5	6.0	5.5	4.0

2″ to 3″ asphaltic concrete on concrete base:							
1 : 3 : 6 mix	6.5	6.0	7.0	6.3	7.5	6.8	5– 8
1 : 2½ : 5 mix	6.0	6.0	6.5	6.0	7.0	6.3	
2″ asphalt block on cement-concrete base:							
1 : 2½ : 5 mix	6.5	6.0	7.0	6.3	7.5	6.8	5– 8
4″ brick (mastic joint filler) on cement-concrete base:							
1 : 3 : 6 mix	6.8	6.2	7.6	6.9	8.3	7.5	
1 : 2½ : 5 mix	6.5	6.0	7.0	6.3	7.8	7.1	6– 8
4″ brick (cement-grout filler):							
1 : 3 : 6 concrete base	5.5	5.0	6.1	5.5	6.7	6.2	5– 8
1 : 2½ : 5 concrete base	5.2	5.0	5.7	5.2	6.3	5.7	
5″ stone block: cement grout filler							
1 : 2½ : 5 concrete base	5.2	5.0	5.7	5.2	6.3	5.7	5– 7

NOTE: Where two depths are given the smaller is for interior areas and the larger for exterior edge depths. Where one is given it applies to interior areas.

Typical recommended pavement sections showing details are given in Chap. VI under the discussion of each type of pavement. The object of this table is to give a tentative basis of estimating the amount of materials and the cost per square yard for the different types suitable for different maximum load conditions.

Table 86 in conjunction with Table 74, page 391, provides a means of computing reliable comparative cost estimates for all ordinary standard types based on equal strength.

with gravel or stone for horse traffic. It is very difficult to get a satisfactory surface on concrete on grades over 5 to 7%.

Classification for Safety of Traffic.—The sheet asphalts and similar constructions are dangerous for high-speed traffic even on fairly level grades during sleet storms or light rains and are not recommended for roads outside of villages except for reconstruction where the large saving due to the use of this type overcomes the factor of reduced safety. Slipperiness can be partially overcome by the use of a larger percentage of small stone in the mix, such as Topeka, Amiesite, Warrenite, etc.

Bituminous macadams, concrete, brick, stone block, water-bound macadams and small stone or brick cubes can be ranked as safe surfaces for high-speed traffic.

Recommended Types.—Bituminous macadams are recommended for Class II traffic and resident village streets; water-bound macadam for Class III traffic; concrete for Class I traffic outside of villages; brick for village business streets; stone block for hills on Class I traffic; asphalt block for extremely heavy Class I traffic. Sheet asphalt, Topeka, etc., are to be avoided for original construction where traffic travels at high speed, but its use for reconstruction has decided advantages from an economic standpoint. Its most suitable location is a resident village or city street or for heavy, slow traffic.

Value of Smooth-riding Quality of Pavements.—This phase of type selection and maintenance limits of expenditure is given in Chap. VII (p. 545).

Failures.—The common causes of failure of different pavements due to structural defects are as follows. The details of inspection are taken up in Chap. XVI.

Stone Block.—Failures rare; will stand lots of abuse in construction.

Asphalt Block.—Failures rare. When they occur due to poor block.

Water-bound Macadam.—Failures rare. When they occur are generally due to poor rock, small-sized stone in top courses, and insufficient rolling or puddling.

Penetration Bituminous Macadam.—Failures not uncommon due to the use of too much soft binder, unequal application, and overheating of binder. The asphalt companies advocate the use of too much bitumen.

Concrete.—Failures not uncommon due to inferior materials, particularly dirty sand, and to poor manipulation, weak mix, and too much water content.

Brick.—Failures not uncommon due to poor brick and careless grouting.

Sheet Asphalt and Topeka Mix.—Failures not uncommon due to overheating and poor mix.

DETAILS OF DESIGN AND CONSTRUCTION OF HIGH CLASS PAVEMENTS

STONE AND GRAVEL FOUNDATION COURSES FOR FLEXIBLE-TYPE PAVEMENTS

Preparation of Subgrade.—It is evident from the pressures to which a road is subjected that the subgrade must be well consolidated before placing the foundation stone. This is usually effected by rolling with a 10- or 15-ton steam roller, exerting a pressure of 350 to 500 lb. per linear inch or wheel width, and is continued until the grade is firm and compact.

The difficulties of consolidation in different soils and the methods of overcoming them are discussed under Inspection (pp. 1289 and 1291).

Kinds of Foundation Courses.—The foundation courses in ordinary use are as follows:

1. Crushed stone.
2. Screened gravel.
3. Field-stone subbase.
4. Pit-gravel subbase.
5. Field-stone subbase bottom course.
6. Pit-gravel subbase bottom course.
7. Quarry-stone or Telford base.

1. Broken-stone Bottom Course.—This style of construction is the one in most general use. Where local stone is abundant and well distributed, such a course will cost[1] from $3.50 to $5 per cubic yard rolled in place; where imported stone is necessary, the cost depends largely upon the freight rate and the length of haul and may run as high as $7. Bottom of this kind is generally used where the total depth of stone metaling does not exceed 6 to 8″ after rolling. Beyond these depths it is often cheaper to substitute subbase or subbase bottom course for a part or the whole of the broken-stone course. (See page 390.)

The method of construction by the New York State Highway Commission is shown in extract from Specifications on page 1434.

Where imported stone is specified or the local stone is suitable for both top and bottom courses, the size used for bottom course ranges from 2¾ to 3¾″ in its greatest dimension; the smaller-sized crusher output is used for the top course, for concrete, and for filler; where the local material is only fit for bottom, the course is made up of stone ranging from 1 to 3¾″ in order to use up the total output of the crusher. The stone smaller than 1″ is used for filler, on the shoulders, and sometimes for the cheaper grades of concrete. In specifying the size of stone for a particular job, economy is considered. Stone of sizes from 1 to 3¾″ is perfectly satisfactory. The only reason for limiting the usual size from 2¾ to 3¾″ is that this practice leaves the 1 to 2¾″ stone for the top course; a uniform grade is important for the top and the size mentioned gives a smooth finish.

[1] All costs are for general comparative purposes and are based on 1926 cost conditions.

The ratio of loose depth to rolled depth is approximately 1.3 to 1.

Where filler is not used in the construction of the bottom course more binder is required for the top; it is probable that the use of filler is the better construction, but it must be of good quality.

The clause concerning teaming in the quoted specifications is a dead letter. Teaming helps to consolidate the bottom, provided it is distributed over the full width and the course watched to prevent loss of shape when the traffic is first turned on or after a long-continued rainfall.

2. Screened-gravel Bottom Course.—Screened gravel 1 to 3½″ in size is used in place of crushed stone; the course is constructed in the same manner as described above, except that a filler containing some clay or clay loam is preferable to a clean sand, and it is often necessary to wet the course in order to consolidate it satisfactorily. It is also advisable to apply a small part of the filler before the course is rolled.

A gravel bottom should be made somewhat thicker than a crushed-stone bottom, as the fragments do not interlock so firmly as crushed stone.

Gravel is suitable for Class III or IV traffic and the choice between screened gravel or crushed stone depends entirely on relative cost. Gravel-bottom courses are not advised for traffic of Classes I and II. Under favorable conditions a screened-gravel bottom course will cost from \$2 to \$3 per cubic yard, rolled in place. A coarse pit-run gravel is preferable to a screened-gravel bottom. A typical specification is given on page 1434.

3. Field-stone Subbase.—Field-stone subbase is constructed, as shown in the cut, of field boulders roughly placed, the intervening spaces being filled with gravel, waste ¾″ stone, or stone chips.

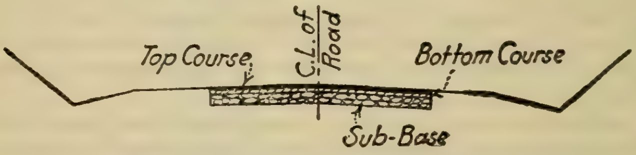


FIG. 144.—Boulder subbase.

No attempt is made to finish the top of the course exactly to line and grade, as any small inequalities can be filled with bottom stone. This type of subbase is suitable for all classes of traffic. The depth varies from 5 to 20″, depending on the soil encountered, traffic the road carries, and also on the size of the available field stone, but for depths of over 8″ the foundation must be constructed as a series of layers not exceeding 8″ each, in order to get proper compaction and filling. In designing a bottom course of this kind, care must be taken to have accurate data as to the average size of stone available. If the demands of a foundation were fully satisfied by a 5″ subbase course, it might still be more economical to use a 7″ course if the stone averaged 7″,

because the extra work of sorting and sledging to a 5″ size would result in a higher cost per square yard than for a 7″ depth.

The amount of stone and filler required per cubic yard in place is approximately as follows:

Loose depth, inches	Rolled depth, inches
6	6
10	8
15	12

This type of base requires approximately ⅓ cu. yd. of gravel or ¾″ stone for filler per cubic yard finished subbase course.

Under favorable conditions this subbase can be constructed for $1.80 to $3 per cubic yard (1922 cost conditions). Specifications are given on page 1425.

4. Pit-gravel or Creek-gravel Subbase.—Stony gravel is satisfactory material for subbase; it can be readily constructed for any depth from 2 to 24″ as required, and where a pit or creek bar is near, the cost of such a course should run from $1.50 to $2.50 per cubic yard. However where the depth is greater than 5″ it must be constructed and compacted in a series of layers no one of which exceeds 5″ in depth.

The ratio of loose to consolidated gravel for such a course is approximately 1.2 to 1.

5. Field-stone Subbase Bottom Course.—Subbase bottom course is essentially the same construction as subbase, except that, as

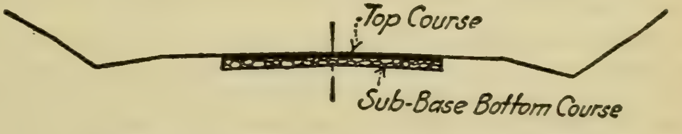


FIG. 145.—Boulder subbase bottom course.

the top course is placed directly upon it, the stone must be more carefully assorted as to size, more carefully placed as to line and grade, and a better grade of filler must be used. Subbase bottom course is advised only under traffic of Classes III and IV. Traffic of Classes I and II requires a middle course (see p. 390).

Crushed stone (crusher run) or coarse gravel makes a satisfactory filler.

The course can be of any depth from 5″ up, depending, as for subbase, on the soil and average size of stone; it is practically impossible to make a large stone bottom of this kind conform exactly to line and grade; a variation of 1″ either above or below grade is usually allowed and the inequalities taken out by the top stone; this requires that the top course must be at least 3 to 4″ deep after rolling.

Subbase bottom is especially applicable for traffic of Classes III and IV on long stretches of road, requiring a depth of 9 to 20″; depths of over 9″ must be constructed in successive layers. It usually costs from $2 to $4 per cubic yard in places where fence stone is available, and by its use the item of higher-priced stone is reduced. On hard foundation soils, however, it is generally better to use 4 to 5″ of ordinary broken-stone bottom course instead of the subbase bottom course even if it is more expensive, because the small-stone construction is more uniform in its resistance to heavy loads and the top course will wear more evenly and longer.

An extract from the 1920 New York State Specifications is given below:

SUBBASE BOTTOM COURSE

"When field or quarry stone is used for constructing the foundation course it shall be of a hard, sound, and durable quality, acceptable to the engineer; the stones shall be placed by hand so as to bring them in as close contact as possible. All stone must be rehandled in placing. Dumping from wagons and leveling off the piles will not be permitted. When quarry stones are used they shall be placed on edge. The depth of single stone shall in no case be greater than the depth specified for the course, the width shall not be greater than the depth, nor more than 9″, and the length shall not be greater than one and one-half times the depth, nor more than 12″. The distribution of the stone shall be of a uniformity satisfactory to the engineer. The long dimension shall always be placed crosswise the road. After laying this course shall be thoroughly rolled with an approved roller weighing not less than 10 tons, and shall then be filled with stone or coarse gravel as directed and again rolled until the stones are bound together and thoroughly compacted; but no gravel shall be used for filling except under written permission of the engineer. All holes or depressions found in rolling shall be filled with material of the same quality and the surface shall be rolled until it conforms to the lines and grades shown on the plans. When field stone is used, approved tailings may be used for filling. In all cases a sufficient amount of fine material (coarse sand or crusher screenings) shall be used to fill all voids. In limited areas where the use of a roller is impracticable, heavy tampers may be used to consolidate the material."

6. Pit-gravel Bottom or Subbase Bottom.—A stony gravel containing not over 15% of loam makes a satisfactory course; the depths vary from 4 to 18″; pit or creek gravel, even when unusually coarse, has from 40 to 60% of fine material; a suitable gravel for pit-run bottom should not contain more fine material which will pass a ¼″ screen than coarse material which will be retained on a ¼″ screen. If there is a large excess of fine, the gravel should be screened and remixed at the bin in proper proportions. Pit-run-gravel bottom should be used only for traffic of Classes III or IV.

The great difficulty in this construction is to get proper consolidation without too much delay. It is advisable to lay a course of this kind at least 2 weeks ahead of the top stone so that traffic and rains may help consolidate the course. The addition of 10% of loam to clean gravel will quicken the consolidation. This can be done either at the pit when stripping, by leaving a thin layer of loam, which runs down with the gravel in loading, or by placing from ½ to 1″ of loam on top of the gravel as it is spread on the road. The author has succeeded in getting rapid consolidation by snatching loaded teams over the loose course with the road roller; the roller continually smooths out the gravel and eases the haul for the teams;

the horses' hoofs and wagon wheels punch into the gravel and pack it down rapidly; a traction engine with lugs on the wheels is also effective in place of a standard roller. Sprinkling helps. A gravel bottom consolidates unevenly and it is always necessary to reshape it somewhat after consolidation; about 5 cts. per cubic yard should be allowed for this reshaping of crown and elimination of humps and hollows.

A properly consolidated gravel bottom will permit a 4-ton load on 3½" tires to pass over it without making a wheel mark over ⅛" deep; this is a simple construction test. This construction has been discussed in some detail as it is the most economical type of bottom in a large number of cases, but it is not generally favored because it is harder to consolidate than the other types of bottom. With a 3" or, preferably, a 4" macadam top it has proved satisfactory on Class III and IV roads.

The cost of a gravel bottom ranges from $1.20 to $2.20 per cubic yard in place, provided the hauls are short.

The depths of gravel are gaged by blocks or lines and the ratio of loose to rolled depth is approximately 1.2 to 1.

7. Telford Base.—Telford base is rapidly going out of use in the United States because of the difficulty of maintaining a top course laid upon it. It seems to be too rigid and is more expensive than subbase or subbase bottom course, costing about $3 to $5 per cubic yard under favorable conditions.

A good description of a Telford construction is given by William Pierson Judson, in "Roads and Pavements." The following quotation is from his book:

"On this subgrade are then placed by hand the stones forming the Telford foundation, which may vary in size as shown below; each stone must be set vertically upon its broadest edge, lengthwise across the road and forming courses and breaking joints with the next course, so as to form a close and firm pavement. The stones are then bound by inserting and driving stones of proper size and shape to wedge the stones in their proper position. All projecting points are then broken with a sledge or hammer so that no projections shall be within 4" of the finished grade line.

"The Telford foundation is then rolled with a steam roller of 10 or more tons' weight, until all stones are firmly bedded and none move under the roller. All depressions are then filled with stone chips not larger than 2½", and the whole left true and even and 4" below the line of finished grade and cross-section.

"A good workman will average about 20 min. in setting a square yard of this Telford foundation, which may be formed of any kind of quarried rock which is most available."

The practice in 1901 in four states was as follows:

TABLE 87.—SIZES OF STONE FOR TELFORD FOUNDATION, IN INCHES

State	Depth as set on edge		Width as set		Length set across road		Remarks
	Maximum	Minimum	Maximum	Minimum	Maximum	Minimum	
New Jersey.......	8	8	4	..	10	..	Alternate end stones, double length
Massachusetts....	6	5	10	4	15	6	2″ gravel rolled on subgrade as base
Connecticut......	8	8	10	6	18	8	Macadam covering formed in one layer
New York........	8	6	10	4	15	6	Used only on unstable ground as foundation for macadam

TELFORD BASE—SPECIFICATIONS (STATE OF CONNECTICUT)

"95. **Description.**—This base course shall consist of a foundation for the surface course or pavement, 8″ in depth unless otherwise specified, constructed on the prepared subgrade, of large stones wedged in place by the addition of smaller ones, in accordance with these specifications.

"96. **Materials.**—The materials for this work shall consist of approved, sound, tough, durable stones, free from clay, loam, or other foreign substances. The pieces shall be approximately rectangular in section, having a depth of 8″ after knapping, a width of from 6 to 10″, and a length of from 8 to 18″. The small stone for filling the voids in the large material shall consist of material at least equal in quality to that of the large stone.

"97. **Construction Methods.**—The Telford stone shall be laid in courses, by hand, with the broad edge down and with the long dimension at right angles to the center line of the roadway. They shall be laid perpendicular to the finished surface in close contact, breaking joints, and shall be wedged in their correct position by inserting and driving, in all places where practicable, small stone of suitable size. All projecting points shall be napped off and the remaining voids filled with small stones, so that the finished surface shall be true and uniform. This base course shall be rolled with a three-wheel power roller, weighing not less than 10 tons, until compacted satisfactorily and true to the grades and cross-sections given. The filling and rolling shall follow the laying of the large stone closely. This course shall not be constructed more than 1000 lin. ft. in advance of the surface course or pavement, unless otherwise permitted by the engineer.

"If at any time, the subgrade material should become churned up or mixed with the Telford stone, the contractor shall, without additional compensation, remove the mixture, reshape and compact the subgrade, and replace the materials removed with clean Telford stone, which shall be rolled and filled until compacted satisfactorily and uniform with the surrounding surface.

"98. **Basis of Payment.**—This week shall be paid for at the contract unit price per square yard for '8″ Telford base course' complete in place, which price will include all materials, equipment, tools, labor, and work incidental thereto."

Distribution of Stone in Foundations.—On light-traveled single-track roads most of the traffic normally keeps to the middle 10 to 12′. It would therefore appear logical to make the central portion of the road thicker than the sides. This applies without doubt

to roads of moderate traffic where the vehicles generally travel in the center of the macadam and only occasionally turn out to pass, but for heavy-traffic double-track roads the assumption is wrong. On such roads the greatest wear and the heaviest wheel load occur about 1′ from the edge of the hard pavement and many of these roads develop the shape shown in Fig. 146. It therefore seems advisable to keep the full depth of metaling for the full width on traffic roads of Classes I, II, and III.

For Class IV traffic the varying thickness indicated in Fig. 147 is applicable.

FIG. 146.—Shallow ruts along edge of Class I traffic macadam road.

Special Foundation Problems.—Long stretches of comparatively level ledge rock, muck, and vegetable loam may be placed under this head.

Where a road is on the surface of ledge rock for any distance, the usual cross-section of part cut and part fill cannot be used because of the high cost of shallow rock excavation for ditches; the grade should be lifted to make the normal section fill and the best available material (not clay) used in its construction. Where conditions of this kind prevail, dirt is usually hard to obtain and often a stone fill is cheaper and also more satisfactory.

The construction shown (Fig. 148) was used for a stretch of 2½ miles on the Le Roy-Caledonia State Highway in New York, where

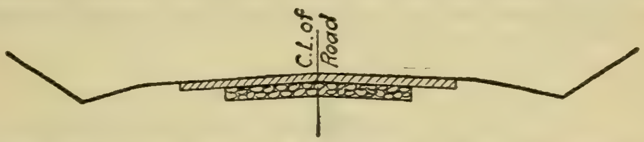


FIG. 147.—Mushroom type of foundation Class IV traffic roads.

ledge rock was encountered as described. The price for the stone fill was $1.23 (1910) per cubic yard in place, constructed as shown; the road was built in 1910 and has given satisfaction; the minimum thickness of top for such a fill is 3 to 4″, as it is impossible to construct it exactly on line and grade; it was found that, by allowing a variation of 1″ either above or below the grade elevation, the fill could be readily constructed, and these small inequalities were taken out with the top stone. A top course having such a variable thickness should be paid for by weight and not by volume in place.

Peat, Muck, Vegetable Loam, or Silt.—Where the material is semifluid, the only solution is a pile and grillage foundation.

Swamps, as ordinarily encountered, can be treated successfully by using a corduroy or mattress foundation covered with a deep fill of gravel or large stone. In some cases where the muck is

comparatively stiff, a gravel or boulder fill alone will give a satisfactory foundation.

Where swamps are crossed by improved roads, the location usually follows the old road, which has often been corduroyed in the past; in such cases the old foundation should not be disturbed; a sufficient additional depth of stone can be added to keep the shape of the section intact.

As an example, the Scottsville-Mumford New York State improvement crossed a 1000′ stretch of muck on the old road loca-

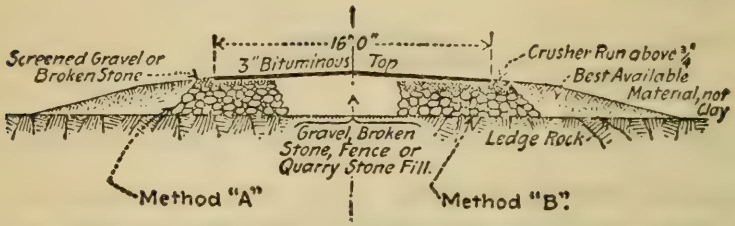


FIG. 148.—Special foundation where road is subjected to flood water ponding in spring of year.

Fill can be made of fence stone, gravel, quarry spalls, stone chips, or run of crusher stone over ¾ in. in size.

METHOD A.—Boulders up to 2 cu. ft. can be used, placing the largest in the bottom of the fill: the top layer must be fairly uniform and not over 8 in. in size and must be roughly placed by hand to reduce the voids as much as possible, provided this layer of large stone is within 4 in. of the bottom of the top course. The top 8 in. to be filled with stone chips or gravel and a cushion of at least 2 in. of screened gravel, stone chips or crushed run of broken stone over ¾ in. size to be placed on top to bring the fill to the correct grade and crown for the top course.

METHOD B.—Same material and manipulation as Method A, except that provided the top of the boulder fill is more than 4 in. from the bottom of the top course the top layer of the boulder fill need not be placed by hand (see sketch, Method B).

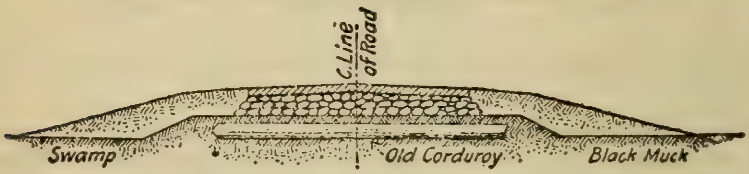


FIG. 149.—Special foundation over old corduroy road through swamp.

tion; it was found that the original cedar corduroy was in good shape; an 18″ depth of large boulders was placed on the old foundation and surfaced with 6″ of broken-stone macadam. This stretch of road has kept its shape and has not settled. It affords a good example of the fact that in many special cases the depth of the stone is determined by trial; the boulders were put on in successive layers of 6″ each until there was no material movement under the roller and then surfaced with the broken-stone macadam. Under a

heavy load the whole roadbed will vibrate for 100′, but the shape remains intact (see Fig. 149).

Economical Foundation Design Macadam Roads.—The economical design of foundation courses may be summarized as follows:

For moderate traffic use pit-run coarse gravel if available, varying the depth to suit the soil. If gravel is not available use a macadam bottom for ordinary soils and field-stone subbase or subbase bottom for bad foundations. The economy in design of macadam roads is greatly increased by utilizing local material, preferably uncrushed, to its fullest extent. If the supply of local material is limited, it should be used for as much of the road as possible and advantage should be taken of the different local supplies by changing the design to allow their use with short hauls.

Uniform designs which disregard limited amounts of local materials often raise the cost from $1000 to $2000 per mile.

Conclusions.—In the design of a road, the amount of material required for the foundation courses can only be approximated. This is the only item in the preliminary estimate that cannot be figured within definite limits. It can be closely estimated if careful data on the soils are obtained from local people and from the preliminary survey, but some leeway must be given the constructing engineer so that he may vary the estimated depths to meet construction conditions and build a consistent road. It will be noted that the depths recommended on page 391 are greater than those shown in most of the state sections throughout the book. This increase in depth is based on the observed action of traffic on the older macadam roads, which, unless recapped with from 3 to 6″ of additional stone, are failing under heavy modern traffic. A macadam foundation is more suitable in northern climates, for nine-tenths of the roads, than a rigid pavement because it is flexible under frost action, and with sufficient depth will hold the heaviest loads, but practice in macadam design and maintenance has heretofore lagged behind the traffic requirements in the matter of depth, while rigid-pavement strength is well abreast of the times. The recent comparisons of the effect of army truck traffic across New York State on rigid and macadam roads is amusing. A considerable mileage of old, thin macadam roads failed in spots, but where a reasonable depth of macadam prevailed no foundation failures occurred. A blare of trumpets hailed the failure of the old cheap inadequtely maintained macadams and great stress was laid on the fact that the rigid types held. This instance is mentioned to illustrate a phase of the present campaign for rigid types which seems unwarranted and dangerous from the standpoint of reasonable road design as it tends to discredit macadam construction. While macadam is not advocated on Class I roads, its use on Classes II, III, and IV should be encouraged (for traffic classification, see p. 6).

Macadam foundation failures are due to insufficient depth, insufficient consolidation during construction, and poor grade filler. The matter of filler is very important. Coarse sand, pea gravel, or stone screenings are preferable for crushed-stone bottom courses and *earth or loam that softens when wet should never be allowed.* Filler

should be a separate item separately paid for. The filler fo[r] boulder or Telford base should be hard, coarse gravel, $\frac{3}{8}''$ crushe[d] stone, or stone chips.

Macadam foundation failures are due to the same cause as con[-]crete failures or brick failures or any other failure—*ignorance an[d] carelessness.* There is no such thing as type failure.

MACADAM SURFACE COURSES

Water-bound Macadam Pavements

Water-bound macadam surface courses are constructed o[f] crushed fragments of suitable rock filled with rock dust and sprinkled and rolled until firm and hard. All types of gravel, boulder, and stone bases are used as described in the first part of this chapter. Standard Specifications are given on page 1454.

Water-bound macadam pavements are satisfactory and economical under light traffic up to about 800 vehicles daily, provided they are systematically maintained and surface ravelling prevented by applications of calcium chloride or light bituminous surface treatments. They have been used successfully under quite heavy traffic, 2000 to 3000 daily, but for a volume of over 500 to 800 daily the maintenance difficulties generally result in the selection of a bituminous-macadam penetration type. The essential advantage of the water-bound type lies in low first cost, simplicity of construction, ease of repair, and safe and easy-riding qualities if the road is well constructed and maintained. Under normal agricultural-district traffic of less than 500 vehicles daily, the final cost of this type of pavement, including yearly maintenance and renewal, is distinctly lower than higher types of surface. When well designed and constructed of adequate thickness (see pp. 390 to 391), they can be used effectively as a base for higher-type surfaces. Water-bound macadam is a very satisfactory type for local town or country roads and for Class III traffic on primary state systems.

Water-bound macadams, including base and top, range in initial construction cost[1] from $1.50 to $3 ($1.90 average) per square yard, depending on character of foundation soil, traffic, and local material supply. The maintenance charge will range from 3 to 10 cts. per square yard, depending on varying conditions; and the renewal charge distributed over the life of the surface will probably average about 5 cts. for Class IV traffic to 11 cts. for Class II traffic per square yard per year, 1922 cost conditions. A surface life of 6 to 12 years is reasonable for this type under a traffic of 300 to 800 daily (10-hr. count) if the road is fairly well maintained, although a considerable number of cases do not fall within these limits (see Chap. VII).

The use of fairly good materials is desirable, but the high standards required for heavy-traffic roads should not be applied to this type, as needless cost is to be avoided under light-traffic conditions. Materials, details of design, and inspection details are discussed later.

[1]1926 cost conditions Western N. Y.

The following recommended designs can be used with assurance reasonably good results.

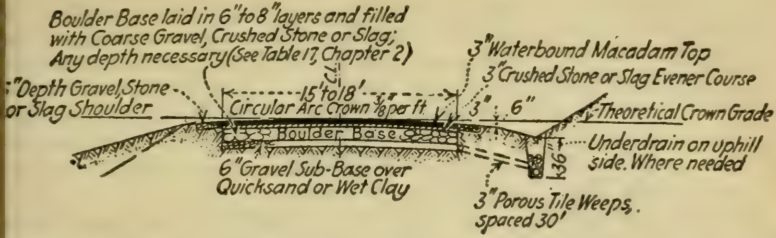
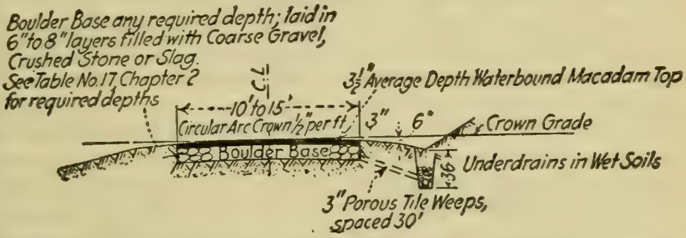
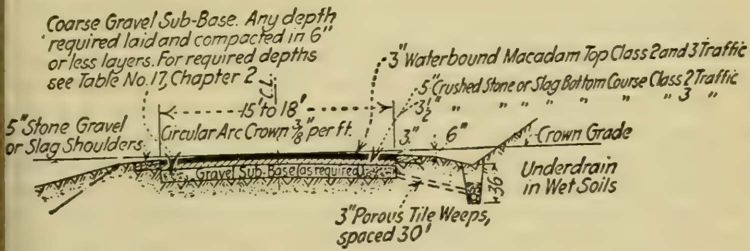


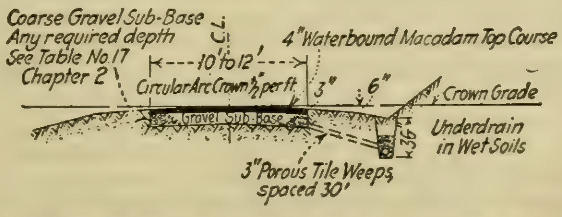
FIG. 150*A*.—Recommended waterbound macadam pavement ction boulder base construction Class II traffic. For discussion of own see page 443.



IG. 150*B*.—Recommended waterbound macadam pavement section boulder base construction Class III or IV traffic.



IG. 151*A*.—Recommended waterbound macadam pavement section gravel foundation Class II or III traffic.



IG. 151*B*.—Recommended waterbound macadam pavement section gravel foundation Class IV traffic.

Recommended Designs.—The accompanying recommended designs represent conservative practice; a large mileage of thinner pavements has been built and has served for a short time with moderate satisfaction; as a matter of fact, no well-constructed macadam road having a depth of at least 80% of the values recommended can be a serious failure, as it can be easily strengthened in the future by the addition of stone depth. It, however, seems undesirable in most cases to resort to resurfacing in too short a period, and for this reason caution should be exercised in reducing the depths shown in districts permitting a legal gross vehicle load of 28,000 lb. (see Figs. 150 and 151, p. 439).

Suitable Materials. *Surface-course Coarse Aggregate.*—Any tough, hard-crushed stone which breaks in roughly cubical form and does not air or water slack is suitable for coarse aggregate. Limestone, granite, gneiss, trap, and hard sandstones are generally satisfactory. For Class III traffic (300 to 800 daily) it is desirable to use a stone having a French coefficient of hardness of 7 or better (6% of wear or less) (see Chap. XI for tests). Stone as soft as 4 French coefficient has been used with moderate success, but where a soft stone is necessary because of the prohibitive cost of a better grade the size should be increased. The usual size of coarse aggregate for top course is 1¼ to 2½″; for soft stone the size should be 2½ to 3½″, using the smaller grades for the foundation course. For purely local roads carrying less than 300 vehicles daily practically any available local stone which does not air or water slack can be used. Crushed slag is suitable under light traffic. Crushed slag is not advocated for top course on the heavier-traffic roads. Crushed slag should weigh at least 1800 lb. per cubic yard loose measure and show a per cent of wear not exceeding 12 by the standard slag abrasion test.

Surface-course Binder.—Limestone screenings make the best filler, as they have considerable cementing quality and bond the stone well. Where the coarse aggregate is trap, granite, or sandstone, it is difficult to get a good puddle, and on the more important roads at least 50% of limestone dust is mixed with the other screenings. Surface oiling tends to minimize the necessity for limestone screenings, but the authors prefer at least 50% limestone dust on water-bound macadam roads on primary state systems. For purely local agricultural roads, the natural rock screenings are used.

Oiling.—There are a number of light asphaltic oils and refined tars on the market which serve well for surface applications. The quality of these bituminous materials is discussed under Maintenance, Chap. VII. Specifications are given in Part III. Personally, the author prefers a good cold-tar product to asphaltic oils for surface application, as they seem to have better penetration and to harden quicker. They are probably a little more slippery and perhaps not quite so durable, but, on the whole, tar is superior to asphalt for surface treatment of water-bound macadam roads. For surface oiling of penetration bituminous macadam, it is probably best to use asphaltic oil where the pavement binder is asphalt and to use the cold, light tar where the pavement binder is a heavy tar.

Macadam Bottom Courses, Coarse Aggregate.—For crushed-stone bottom courses, any stone which will stand the necessary rolling to compact and which does not water slack is suitable. Crushed slag weighing not less than 1800 lb. per cubic yard loose makes an excellent material. No maximum per cent of wear is recommended. The cheapest available source is generally used, but it is necessary to decide what source will be used and to set the maximum per cent of wear for any specific contract to prevent argument and the use of needlessly inferior material. The size usually specified is 2½ to 3½″, but this is merely to permit the use of the 1¼ to 2½″ size for top, and a perfectly satisfactory bottom can be constructed of well-mixed stone ranging in size from ¾ to 3½″, provided pockets of fine and coarse stone are not permitted. Tailings can be used if knapped to the proper size.

Macadam Bottom Filler.—Coarse sand, stone, or slag screenings make the best filler; sandy loam is satisfactory on light-traffic roads. Filler is very important; it should be a separate item, separately paid for, and no material which softens when wet should be used, even for unimportant roads. *A considerable number of macadam failures are directly traceable to soft filler.*

Boulder-base Coarse Aggregate.—Any ordinary boulder or quarry stone is suitable provided it is not rotten. Large boulders must be sledged to suitable size. Maximum size is usually placed at 8″ for any dimension, with the depth thickness not greater than the finished depth of the course (see Specifications, p. 432).

Boulder-base Filler.—Crushed stone or slag or coarse, hard gravel containing not over 15% of loam is satisfactory. Fine sand or loam should never be used.

Gravel Bottom and Subbase.—A coarse, hard gravel containing not over 15% of loam and having a grading in size of at least 50% retained on a ¼″ mesh screen makes an excellent base. If the pit run is non-uniform and excessively fine, it should be screened and remixed in the proper proportions of fine and coarse.

Amount of Material Required per Cubic Yard of Consolidated Macadam.—*Top course* requires approximately 1.3 cu. yd., loose measure, of crushed stone (1¼ to 2½″ size) and approximately 0.5 cu. yd. stone screenings for binder and wearing course. The weight of this material will vary according to the kind of stone used. Commercial plants will furnish data of loose-measure weights of their standard sizes. Table 88 gives a fairly close means of estimating weight.

In western New York, for limestone having a specific gravity of approximately 2.7 (170 lb. per cubic foot), the total weight of stone and screenings per cubic yard of finished water-bound macadam top course, including the wearing course, is close to 4400 lb. From 50 to 80 gal. of water are required to puddle a cubic yard of top course.

Macadam bottom course requires approximately 1.3 cu. yd. loose measure of crushed stone, slag, or screened gravel ranging in size from 2½ to 3½″ and approximately 0.35 cu. yd. of sand or stone screening filler. Where the bottom is constructed of mixed sizes from 1¼ to 3½″, it requires approximately 1.25 cu. yd. loose per consolidated yard of finished macadam.

Table 88.—Weights[1] of Materials

Kind	Specific gravity	Broken stone, pounds per cubic yard	
		Loose spread 45% voids	Compacted 30% voids
Trap	2.8	2590	3300
	2.9	2680	3420
	3.0	2770	3540
	3.1	2870	3650
Granite	2.6	2400	3060
	2.7	2500	3180
	2.8	2590	3300
Limestone	2.6	2400	3060
	2.7	2500	3180
	2.8	2590	3300
Sandstone	2.4	2200	2830
	2.5	2310	2940
	2.6	2400	3060
	2.7	2500	3180

[1] "Asphalt Association Pocket Reference."

Pit-run gravel subbase requires approximately 1.2 cu. yd. loose measure per consolidated cubic yard.

Field-stone boulder subbase requires 1 cu. yd. of boulders per cubic yard of finished course where only one layer of uniform-sized boulders is used. Such a base requires 0.5 cu. yd. of gravel or crushed-stone filler. Where the depth of the base is greater than the average-sized boulder, approximately 1.25 cu. yd. of boulders are required per cubic yard of finished base, with from 0.3 to 0.4 cu. yd. of gravel or crushed-stone filler.

Design.—The design of macadam pavements considers the proper use of local materials, the depth required on different soils, width, crown, etc. Pages 366 to 392 developed the detail theory of total macadam depth under different traffic and soil conditions. Table 74 (p. 391) gives these depth data. Having established the total depths, alternate estimates are made on the basis of utilizing gravel, boulder, or crushed-stone base courses. The variations in depth of the macadam surface on these different bases were developed on page 390. The most economical combination is adopted (for example, see Official Report, p. 1095). Where boulder and gravel are both available, it is generally better and more economical to use boulder base, gravel filled, with a thinner macadam surface. While it is desirable to keep the depth of top course to a minimum on account of the high cost of this part of the pavement, it is not safe to use less than a 3″ consolidated depth on account of the tendency to ravel and kick out.

Widths.—Widths were discussed in the chapter on Sections (pp. 130 to 142).

Crown.—A circular-arc crown is a good form. For the narrow single-track local roads, a total crown of ⅜ to ½″ per foot of half width is a good rule. For the wider roads 16 to 18′ and for village streets, the crown should be about 5/16 to ⅜″ per foot on account of future use of the macadam as a base for asphaltic concrete or small block surfacings. One-way banking on sharp curves is desirable for rural roads carrying over 300 vehicles daily, but is a useless refinement on light-traffic local roads.

See Chap. III (p. 123) for complete discussion of crowns.

Superelevation on Curves.—Superelevation was discussed in Chap. III (p. 127).

Limitations Imposed by Steep Grades.—See page 425.

Specifications.—See Part III (pp. 1454 to 1455).

Construction Equipment.—Equipment is discussed in Chap. XV (pp. 1261 to 1262).

Inspection Details.—See Chap. XVI (pp. 1272 to 1296).

General Maintenance Methods.—Detail maintenance methods and costs are given in Chap. VII.

Well-defined holes are repaired by cutting out the edges square and vertical, filling with regular top stone, rolling, and puddling as in the original construction. Small depressions are usually remedied by filling with cold patch or screenings and oil. Surface pitting is remedied by oiling and cover. Shoulders are built up by scraping fresh dirt or by the addition of gravel or stone. The maintenance of ditches, guard rail, culverts, etc. is similar for all types of improvement.

Penetration Bituminous Macadam Pavements

General Discussion.—Bituminous macadam is what the name implies, a macadam pavement bound with bituminous material. The larger stone fragments, ranging in size from 1¼ to 2½″, depending on the depth of the course, are spread and rolled. A heavy grade of refined tar, residuum bituminous material, or fluxed natural asphalt is then poured hot, either by hand or machines, into the voids of the stone so that the stone fragments are covered with a thin coat of bituminous material; ¾″ stone or dustless screenings are spread over the surface, which is broomed and rolled until the voids are filled. If a bituminous flush coat is to be used, the excess filler is broomed off and the surface application of bitumen completed. Where the flush coat is not applied, a wearing coat of clean screenings is spread over the surface.

The amount of bituminous material used as binder varies from 1.50 to 1.75 gal. per square yard, depending on the depth of the course. The amount used for flush coats ranges from 0.2 to 0.5 gal. per square yard. Standard Specifications are given on page 1458.

Penetration-bituminous-macadam pavements are satisfactory and economical under normal traffic conditions ranging from 800 to 2000 vehicles daily (10-hr. count in summer season). They have been used quite extensively for traffic as low as 300 daily and in a few cases with moderate success up to 6000 daily, but caution should

be exercised in their selection for roads carrying more than 2000 daily. The essential advantage of this types lies in its ability to provide very satisfactory road service at less initial cost than any type of rigid pavement. Under moderate traffic the final cost, including maintenance and renewal, compares favorably with any type of road. When well designed and constructed, with thickness recommended on page 391, these roads can be utilized in the future as bases for higher-type surfacings. They are a very satisfactory type for Class II traffic and for residential village and city streets. They are not seriously damaged by settlement and can be easily and quickly repaired. They are safe for high-speed travel; they will ride well if carefully constructed, but under careless inspection, where the bitumen is unequally applied, they gradually develop humps and hollows which are very disagreeable to fast traffic. This type of pavement requires careful construction and ample stone depth. They are resilient under steel-tire traffic as well as under ordinary motor traction, and for this reason are used extensively in England. They have a pleasing neutral color.

Bituminous macadams, including base and top, range in initial cost (1922 cost conditions) from \$1.60 to \$3.40 (\$2.20 average) per square yard, depending on varying conditions of foundation soil, traffic, and local materials; the maintenance charge will range from 2 to 6 cts. per square yard per year, depending on all sorts of conditions, and the surface renewal charge distributed over the life of the pavement will probably average about 10 cts. for Class III traffic, 12 cts. for Class II traffic to 20 cts. for Class I traffic per square yard per year, 1926 cost conditions.[1]

The use of excellent materials is desirable, but for the type of traffic usually served best by this pavement (Class II) excessive refinements of materials or manipulation which raises the cost needlessly may well be avoided. Materials, details of design, and the essentials of inspection are later discussed. The following designs can be used with assurance of reasonable success.

Recommended Design.—The recommended designs represent conservative practice. A large mileage of thinner pavements has been constructed and has served quite satisfactorily for a considerable terms of years under favorable traffic conditions. As a matter of fact, it is rare that any well-constructed bituminous-macadam road of 80% of the thickness recommended is a serious failure, for if traffic proves too severe for either the foundation strength or surface resistance to wear, the old pavement can be strengthened by additional stone and the pavement made satisfactory by capping with a more resistant surface at considerably less cost than is required for a rigid type of pavement.

It is, however, undesirable to resort to additional surfacing in too short a period, particularly on the score on depth weakness, and it seems desirable to avoid much reduction in thickness below the depths recommended where local traffic laws permit a 28,000-lb. gross vehicle load limit. A surface life of 8 to 12 years is reasonable for this type when fairly well maintained under traffic of 800

[1] Renewal costs based on maximum allowable Vialog coefficient of 250 without excessive maintenance (see p. 551).

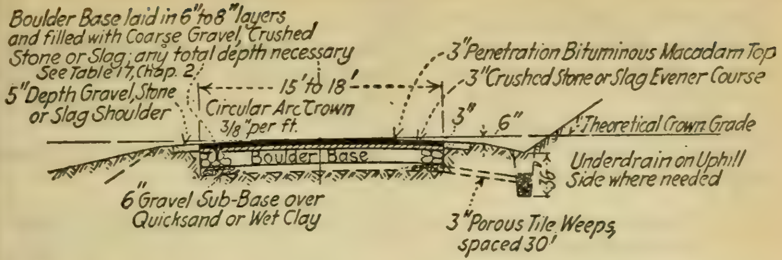


FIG. 152*A*.—Recommended penetration bituminous macadam pavement section, boulder base construction Class II or II*A* traffic. For discussion of crown see page 448.

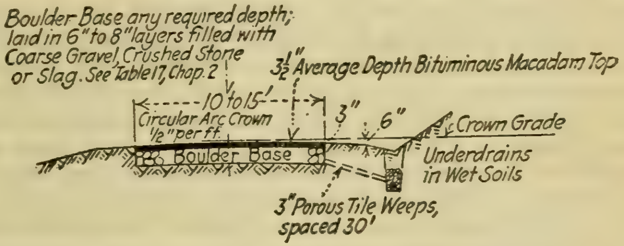


FIG. 152*B*.—Recommended penetration bituminous macadam pavement section, boulder base construction Class III or IV traffic.

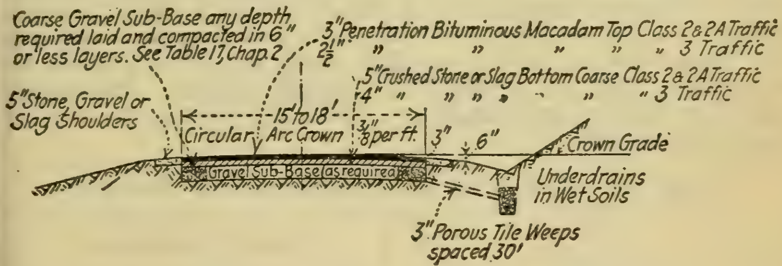


FIG. 153*A*.—Recommended penetration bituminous macadam pavement section, gravel base construction Class II, II*A* or III traffic.

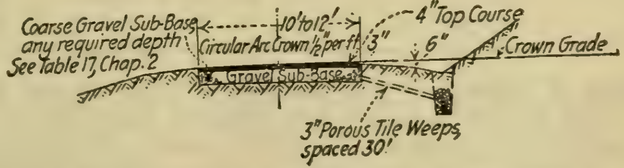


FIG. 153*B*.—Recommended penetration bituminous macadam pavement section, gravel, base construction Class IV traffic.

to 2000 daily, although a considerable number of cases do not fall within these limits (see Chap. VII).

Suitable Materials.—Materials for foundation courses were discussed under Water-bound Macadam (p. 441). Top-course materials are crushed stone and bitumen. Typical specifications are given on page 1383.

Crushed Stone.—Top-course crushed stone consists of three sizes, specified as follows:

Coarse aggregate....................	1¼ to 2½″ size
Intermediate size....................	¾ to 1¼″ size
Dustless screening....................	⅛ to ¾″ size

The stone must be hard, tough, and clean. The coarse aggregate 1¼ to 2½″ size must be uniform and must not contain over 15% of stone smaller than 1¼″ in size; this is important. Under heavy traffic where trap or the harder granites are available, a minimum French coefficient of hardness of 8 is desirable (5% or less of wear). Very good results can be obtained with a minimum hardness coefficient of 7 (6% or less of wear), and this is the usual minimum limit where limestones and the harder sandstones are the prevailing formation. Under light traffic and where hard rock is very expensive, a coefficient as low as 5 has been used, but under such conditions it is desirable to increase the size of the coarse aggregate to 2½ to 3½″ and to use a harder grade of rock for the screening incorporated into the seal coat.

Bitumen.—Either asphalt or refined tars of the binder grade can be successfully used. Detail specifications are given on page 1388. For penetration bituminous macadam, an asphalt binder is preferable. The proper consistency of asphalt binder is about the only feature in design which varies with traffic and climatic conditions. The asphalt authorities believe that Table 89 is a safe guide for determining this requirement of asphalt binder. The author prefers 80–100 for medium-heavy traffic for western New York climatic conditions.

TABLE 89.—VARIATION IN PENETRATION OF BITUMEN

Traffic	Climatic temperatures		
	Low	Moderate	High
Light..........................	120–150	90–120	80–90
Medium..........................	90–120	90–120	80–90
Heavy..........................	80– 90	80– 90	80–90

Amounts of Material.—The amounts required for the foundation courses are given under Water-bound Macadam (p. 441).

For penetration top course, records in western New York show that the proportion of sizes used per cubic yard of finished top (limestone aggregate) are approximately as follows:

	Per Cent
$1\frac{1}{2}$ to $2\frac{1}{2}''$ size crushed stone	65
$\frac{3}{4}$ to $1\frac{1}{2}''$ size	20
Dustless screenings	15

The total weight of all sizes of limestone, sp. gr. 2.7 (170 lb. per cubic foot solid), is about 4250 lb. per cubic yard for a $2\frac{1}{2}''$ consolidated depth of finished macadam and about 4350 lb. per cubic yard for a $3''$ consolidated depth.

The following table contains data released by the Asphalt Association:

Asphaltic Macadam Wearing Course
($2\frac{1}{2}''$ consolidated thickness)

Materials	Pounds per square yard
Coarse stone	227
Intermediate stone	45
Screenings	25
Asphalt	19

Bituminous Binder.—For single-coat work on steep grades, 1.5 gal. per square yard applied in one coat is satisfactory for $2\frac{1}{2}''$ depth of top and 1.75 gal. per square yard for the $3''$ depth. Where seal coats are used on the lighter grades, 0.4 to 0.5 gal. is generally used. Asphalt binder for penetration macadam weighs about as follows:

Asphalt

Specific gravity	Weight, pounds per gallon
1.00	8.33
1.02	8.50
1.04	8.66
1.06	8.83

Design.—The principles of design are essentially the same as for water-bound macadam; that is, a good design considers the varying depth required for the prevailing soils, the most economical use of local materials, width, crown, and depth of top course. To determine total depths, reference is made to Table 74 (p. 391). Having decided on the depths required, alternate estimates are prepared on the basis of utilizing gravel, boulder, or macadam foundation courses. The variations in depth of macadam over gravel or boulder bases were developed on page 390. The most economical combination is adopted. The important point is

that a real design shall be made, considering soil conditions and local material. Rigidly standardized uniform depth over varying soils is to be avoided (see sample design report, p. 1095). Where a macadam bottom or evener course is used, it is permissible to reduce the top to a 2½" thickness under fairly light traffic. Under heavy traffic a depth of 3" is recommended. Some states use a 2" depth of top, but experience has not been entirely satisfactory with depths of less than 2½" where a limestone aggregate is used.

Widths and Crown.—Widths were discussed in detail in Chap. III. Extra widening at sharp curves is desirable (see Tables 37*A* to 37*B*, p. 132). Village-street widths are outlined in Chap. III.

A circular arc crown is a good form. The total difference in elevation between center and edge of pavement is usually based on 5/16 to 3/8" multiplied by the half the width in feet. For the usual road 16 to 20' in width, the slope of 5/16" per foot seems satisfactory. For village streets of greater width it is just as well to use the crown recommended for sheet-asphalt pavements as given on page 505.

On sharp curves on rural highways, one-way banking is desirable except on high fills. Ordinary practice in regard to banking slopes is given on page 127.

Steep Grades.—See pages 425 and 101 for limitations of use on steep grades.

Comparative Costs.—The cost of one-coat 2½" bituminous top, using 1.5 gal. per square yard, will range from 80 cts. to $1, and a 3" one-coat top, using 1.75 gal. per square yard, from $1 to $1.20 a square yard. The flush coat using 0.4 gal. per square yard will add about 8 cts. to the above costs. For comparison with macadam, a fair set of prices is (1922 cost conditions):

	Price per Square Yard
3" water-bound macadam top course.....	$0.70
2½" bituminous top, one coat of bitumen	0.85
2½" bituminous top, flush coat..........	0.90
3" bituminous top, one coat of bitumen...	1.00
3" bituminous top, flush coat..........	1.10

Specifications.—See Part III, pp. 1458 to 1459.

Construction Equipment.—See Chap. XV (pp. 1262 to 1263).

Inspection Details.—See Chap. XVI (pp. 1296 to 1297).

General Maintenance Methods.—For detail methods and suitability of materials, see Chap. VII.

Well-defined holes are repaired by digging out the top course for the entire depth, out to the outer limits of the depression; squaring up the edges, and then filling in with regular top-size stone, 1¾ to 2½"; rolling or tamping; pouring with the same type of binder as the original course; adding ¾" stone and screenings as in the original construction. Small holes are repaired by filling in with cold patch or screenings, and oil and surface pitting or livening of the bituminous binder is remedied by surface oiling, using an asphaltic oil if the binder is asphalt and a light tar if the

binder is a refined tar. Shoulders, ditches, guard rail, etc. are routine procedure for all types of road as previously described.

RIGID-BASE PAVEMENTS

Cement-concrete Pavements

The usual concrete pavement is composed of a series of slabs separated by expansion and contraction joints. The concrete is generally the same mix for the entire depth, although some pavements have a special rich surface mix. Varying amounts of steel are used in the form of dowels, corner bars, tie bars, and mesh. Modifications of this type are constructed, such as Hassam concrete and concrete with thin bituminous surfaces. Specifications on page 1470 summarize the detail methods of construction. A large mileage of concrete pavement has been constructed on rural highways within the past few years and has met with popular approval.

From the engineering standpoint, concrete pavements are an excellent type for moderately heavy traffic (2000 to 5000 vehicles daily, 10-hr. count in the summer season). They have a gritty surface, which is safe for high-speed travel. They ride well if carefully constructed, particularly if built in separate strips 8 to 10′ wide, but under the usual inspection they are often rather bumpy and on grades of over 5% it is very difficult to get a smooth-riding pavement even with the greatest care. They have a bad glare in bright sunlight, but are easy to follow at night. For village or city streets, they do not look so well as pavements having a more neutral color, and in case they are used on curbed streets a high curb should be designed to permit future surfacing on top of the concrete. Concrete pavements cost from \$2.50 to \$4 per square yard (\$3 average, 1926) for new construction; the maintenance charge will range from 0.3 to 3.0 cts. per square yard per year, depending on all sorts of conditions, and the surface renewal charge distributed over the life of the pavement will probably average about 10 to 14 cts. per square yard per year, 1926 cost conditions.[1] They are an excellent type for the lower-limit Class I roads or the higher-limit Class II roads where there is no large percentage of steel-tire traffic, but from an economic standpoint they should be used with caution for traffic of less than 1500 vehicles daily. They are more suitable for country highways than for village or city streets except alleys.

Concrete pavements give the advantages of the rigid-pavement type generally at less initial cost than other standard pavements, provided care is taken not to spend too much on refinements. When surface failure occurs they can be used effectively as a base for any of the standard paving surfaces. The essential advantage of the concrete pavement lies in its temporary use as a surfacing and its comparatively permanent value as a rigid base. To derive the most benefit from this combination of uses, it is necessary to

[1] Renewal costs based on maximum Vialog coefficient of 250 without excessive maintenance (see p. 551).

avoid excessive expenditure on refinements which have only a minor effect in increasing the life of the surface. A design which results in a surface life of 8 to 15 years, depending on traffic volume, seems rational for this type, considering the cost and the doubtful success of attempting to increase this period. This requires the use of excellent material and careful manipulation, but it does not require laboratory standards of mixing and curing nor does it require the extreme refinements of true reinforced-concrete design.

The cost of concrete pavements has been gradually increased by various refinements in materials, richness in mix, care in curing, joint details, reinforcement, etc. The object of all the refinements above 1 : 2½ : 5 concrete suitable for paving base of two-course pavements is to produce a wearing surface for traffic which will serve satisfactorily for a reasonable length of time before recapping with some standard form of renewal surface. Eventually, all concrete roads will probably serve as bases for asphaltic concretes, brick, asphalt block, stone block, or some form of repairable surface. It seems probable that the limit of justifiable expenditures for additional refinements in design and construction has about been reached, and in some cases exceeded. No matter what care is taken, spauling at joints, surface scale and pitting, vibratory disintegration, and weather action produce a rough unsightly surface in a comparatively short time, and it seems good policy to get merely a reasonably good concrete of adequate depth with the idea of resurfacing as it is needed. There is considerable disagreement concerning the practical limitations of materials, manipulation, etc. to carry out this general policy, but the following data can be used with assurance of reasonably good results.

Recommended Design (Concrete Pavements).—The recommended designs represent conservative practice. A large mileage of thinner roads has been built and has served quite satisfactorily for short periods of time. Any well-constructed concrete road of 6½″ average depth or more cannot be a serious failure, for if the traffic proves too severe a test for the concrete as constructed it can be protected and strengthened by capping with some standard form of surface which will make the road suitable for the heaviest modern loads.

It is, however, undesirable to resort to additional surfacing in too short a period, particularly on the score of depth weakness, and there seems to be considerable doubt as to the advisability of reducing strength below the limits shown in the following sections where local traffic laws permit a 28,000-lb. gross vehicle load.

These designs are based on the general line of reasoning outlined in the discussion following the sample designs and theory developed pages 392 to 427.

Recommended Design 1 (see Fig. 154). *Suitability.*—Rural highway traffic range of 4000 to 6000 vehicles daily (10-hr. count in summer season) in localities having a 28,000-lb. gross vehicle load limit.

Width.—Twenty feet constructed one-half at a time.

Crown.—Circular-arc radius 240′. Edge 2⅜″ below center line.

Concrete.—A 1 : 1½ : 3 mix with cement content not to exceed 1.9, and crushing strength, 28-day age, of from 3000 to 4000 lb. per square inch.

Transverse Joints.—Three-eighths-inch premolded asphalt spaced 33′, care being taken to insure vertical position of joint. Joints to be ½″ deeper than pavement and cut off after completion of pavement. Concrete to be rounded with an edge radius ¼″ on both sides of joint. Joints to be backed with 16-gage steel plates, ½″ less depth than pavement on grades of 4 % or more to insure vertical position. *No dowels or grooves at joints.*

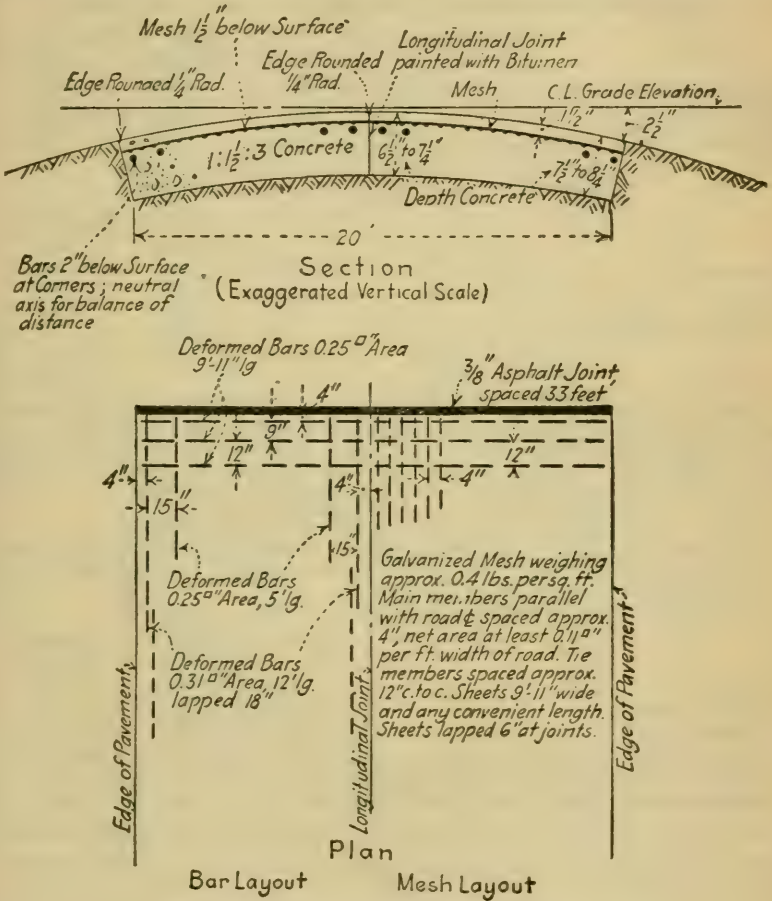


FIG. 154.—Recommended Design 1.

Depth of Concrete.—Based on Table 86 (p. 426).

	Outside Edge, Inches	Interior Areas, Inches
Ordinary soils	8¼	7¼
Gravel or macadam	7½	6½

Over freshly back-filled culvert trenches over 5′ wide increase depth and place bottom reinforcement to conform to culvert slab practice.

Reinforcement.—Combination of mesh and bar. Galvanized mesh to weigh not less than 0.4 lb. per square foot with the main members having an effective area of not less than 0.11 sq. in. per foot width of mesh and spaced not over 4″ C. to C., the tie members to be spaced not over 12″

C. to C. Size and spacing of corner bars based on formula $S = \frac{2.4W}{d^2}$, with W = 14,000 lb. (see p. 415). Percentage area of reinforcement of corner bars approximately three-tenths of 1 %. Tie bars, arbitrary assumption as shown.

QUANTITIES REQUIRED PER 100′ OF ROAD FOR THIS DESIGN

	New Grading	Resurfacing Jobs
Concrete, cubic yard	47.85	44.77
Mesh, square feet	2100	2100
Steel, pounds	860	860
Expansion joints, linear feet	60	60

APPROXIMATE COST (1922) PER SQUARE YARD

	New Grading	Resurfacing Jobs
Concrete	\$2.70	\$2.59
Mesh	0.28	0.28
Steel	0.10	0.10
Expansion joints	0.03	0.03
Total	\$3.20	\$3.00

A 9¼″ depth of plain concrete which is equal in strength to this design costs approximately \$3.40 per square yard for new grading conditions.

Recommended Design 2 (see Fig. 155). *Suitability.*—For a rural highway traffic range of 1500 to 4000 vehicles daily (10-hr. count in summer season) in localities having a 28,000-lb. gross vehicle load limit.

Width.—Eighteen feet constructed one-half at a time.

Crown.—Circular-arc radius 200′. Edge 2″ below center line.

Concrete.—A 1 : 1½ : 3 mix with cement content not to exceed 1.9, and crushing strength, 28-day age, of from 3000 to 4000 lb. per square inch.

Transverse Joints.—Same as Design 1.

Depth of Concrete.—Based on Table 86 (p. 426).

	Outside Edge, Inches	Interior Areas, Inches
Ordinary soils	8½	7¾
Macadam or gravel	7¾	7

Over freshly back-filled culvert trenches over 5′ wide increase depth and use bottom reinforcement to conform to standard culvert slab practice.

Reinforcement.—Bars only. Size and spacing of corner bars based on formula $S = \frac{2.4W}{d^2}$, with W = 14,000 lb. Percentage area of reinforcement of corner bar approximately one-fourth of 1 %. Tie bars, arbitrary assumption as shown.

QUANTITIES PER 100′ OF ROAD FOR THIS DESIGN

	New Grading	Resurfacing Jobs
Concrete, cubic yards	44.44	41.97
Steel, pounds	1110	1110
Expansion joints, linear feet	54	54

APPROXIMATE COST (1922) PER SQUARE YARD

	New Grading	Resurfacing Jobs
Concrete	\$2.83	\$2.63
Steel	0.14	0.14
Expansion joints	0.03	0.03
Total	\$3.00	\$2.80

A plain concrete pavement of equal strength costs about $3.30 per square yard.

Recommended Design 3 (see Fig. 156). *Suitability.*—For rural highway traffic of less than 1500 daily. For these traffic conditions a concrete pavement is rarely justified from an engineering standpoint. Local demand, however, sometimes requires this type under these conditions, and for the purposes of expediency it is often desirable to meet the demand. Under

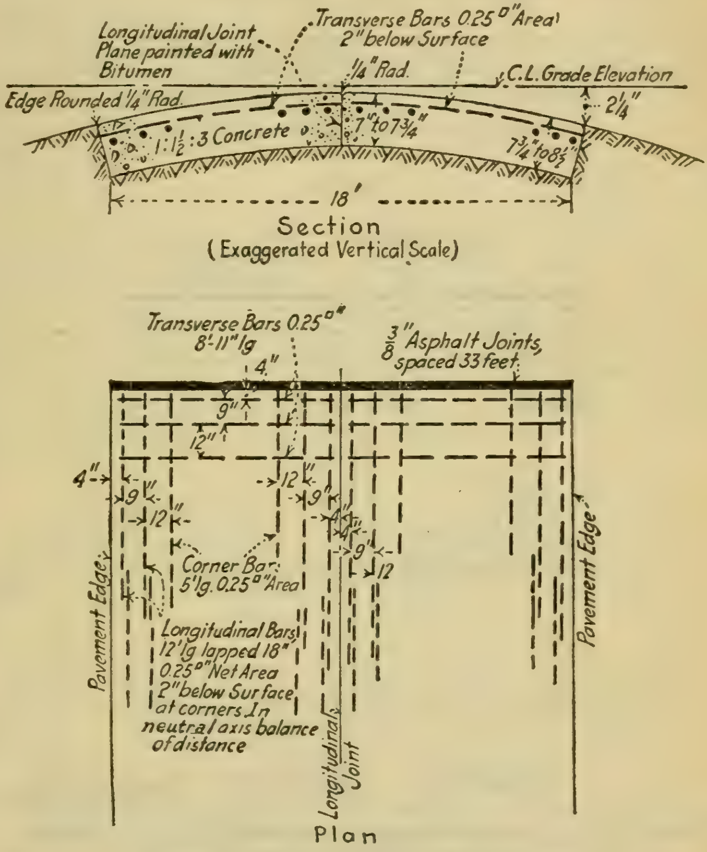


FIG. 155.—Recommended Design 2.

these conditions it is just as well to cut the first cost to a minimum and design the pavement with the idea of recapping with asphalt, etc., as soon as it shows the need. It should, however, be made strong enough so that an asphalt surface will raise its strength to that required for main-road loads.

Width.—Sixteen to eighteen feet recommended, constructed one-half at a time, or if full width is constructed at once, use submerged longitudinal steel joint.

Crown.—Circular-arc radius 200′. Edge 2″ below center line.

Concrete.—A 1:2:4 mix with cement content of not over 1.7, and 28-day crushing strength of 2500 to 3500 lb. per square inch.

Transverse Joints.—Same as Design 1.

Average thickness of concrete 6½ to 7″ for construction on new grading ordinary loams and clays, based on formula $d = \sqrt{\frac{1.5W}{S}}$, with W = 12,000

and $S = 360$ lb. For gravel soils or resurfacing on top of old macadam cut depth ½″ below formula.

Reinforcement.—Corner bars based on formula $S = \frac{2.4W}{d^2}$. Percentage area approximately four-tenths of 1%. Single side tie bar.

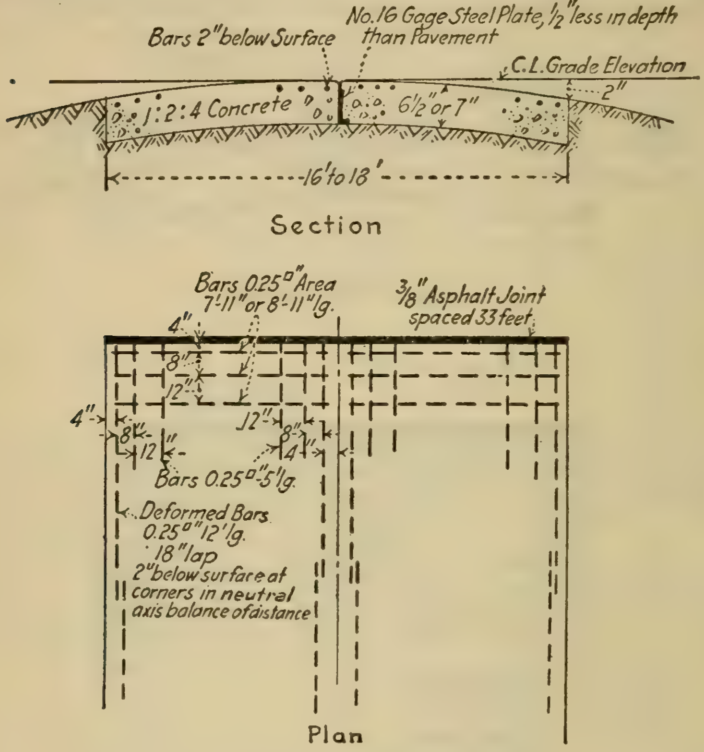


FIG. 156.—Recommended Design 3.

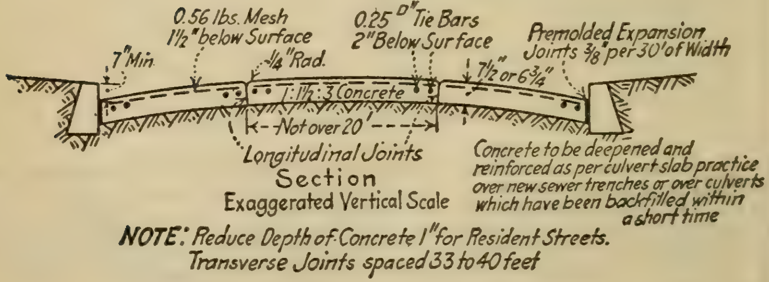


FIG. 157.—Recommended Design 4.

QUANTITIES PER 100′ OF 16′ ROAD FOR THIS DESIGN

	New Grading	Resurfacing Jobs
Concrete, cubic yards	34.6	32.1
Steel, pounds	820	820
Expansion, linear feet	48	48

APPROXIMATE COST (1922) PER SQUARE YARD

	New Grading	Resurfacing Jobs
Concrete	$2.24	$2.08
Steel	0.12	0.12
Expansion	0.02	0.02
Longitudinal steel joints	0.04	0.04
Total	$2.42	$2.26

Recommended Design 4 (see Fig. 157). *Suitability.*—For village business street, 28,000-lb. gross vehicle load limit.

Width.—Any desired total width constructed in longitudinal strips of from 10 to 20′ width. Longitudinal joints painted with bitumen. Expansion along gutter line and at intervals of 33 to 40′ across road.

Crown.—Circular arc producing depth of edge below center line as shown on charts (p. 505).

Curb.—Seven inches high to permit future surfacing of asphaltic concrete or thin block.

Concrete.—A 1:1½:3 mix with cement content of not to exceed 2.0, and crushing strength, 28-day age, of 3000 to 4000 lb. per square inch.

Transverse Joints.—Three-eighths inch premolded asphalt spaced 33′. Special care to keep straight and at right angles to curbs.

Depth of Concrete.—Seven and one-half inches uniform on loams and clays. Six and three-fourths inches uniform on gravels and coarse sands.

Reinforcement.—Same as Design 1 except direction of main members of mesh, which are at right angles to the direction shown in Design 1, where longitudinal joints are more than 12′ apart.

Mesh.—To weigh not less than 0.56 lb. per square foot and to have an effective area of 0.14 sq. in. per foot width. Corner bars three-tenths of 1 % of section area for 30″ back from corners.

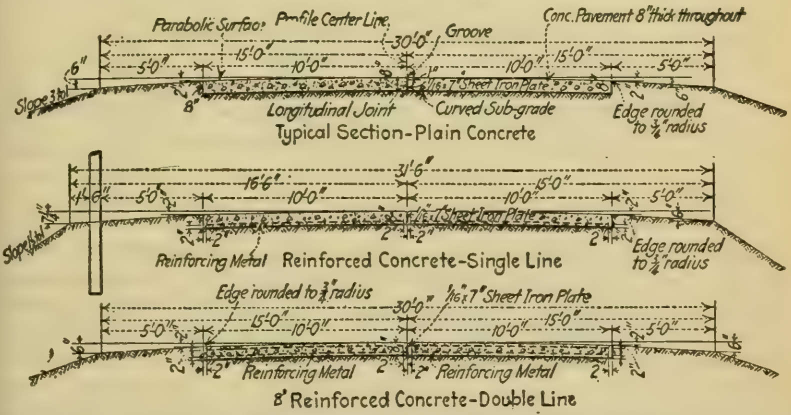


FIG. 158.—State of New Jersey (1922) Standard plain and reinforced concrete pavements.

Summary of Current Practice.—The tabulation (p. 462) gives a quick means of noting the essential features of current practice. This table was compiled by the Portland Cement Association in 1922. The typical sections following show standard sections of various design:

Materials.—The materials required are cement, gravel, stone or slag, sand or screenings, water, expansion joints, reinforcement, and joint plates.

Cement.—The requirements of the Portland cement have been quite well standardized and the required quality can be obtained without much difficulty. All cement should, however, be tested and approved before use.

Cement specifications are given on page 1387.

Cement tests are described in Chap. XI (p. 734).

Gravel and Broken-stone Aggregate.—The essential qualities of the coarse aggregate are that it be a clean, hard, well-graded size of crushed-rock or screened-gravel product.

Where trap rock and the harder granites are available, the minimum hardness requirement for crushed stone is generally placed at French coefficient of 8 (5% of wear). Where the limestones, hard sandstones, and granite hardheads are the most

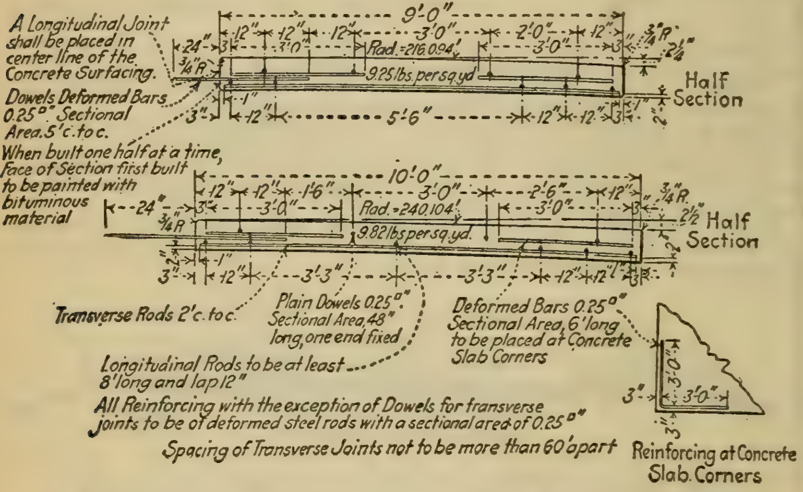


FIG. 159.—Massachusetts concrete road section (1922).

feasible source of supply, the minimum French coefficient can be dropped to 7 (6% of wear) with very good results. In exceptional cases a value as low as 6 (7% of wear) has been used with moderate success, but anything below 7 is risky for this type of pavement. The pavement is expensive and it is poor policy to use inferior materials which reduce the effectiveness of the result. The standard gravel abrasive test giving a 15% wear is about equivalent to a 5% wear of crushed-stone Deval test (see Chap. XI p. 742).

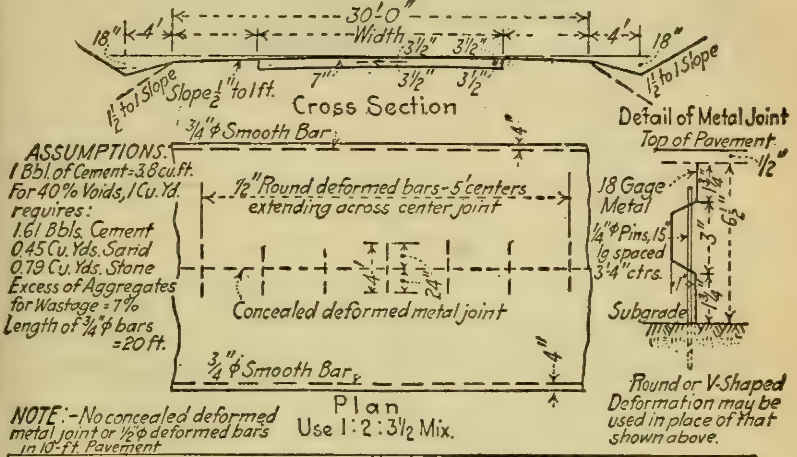
A graded size is desirable, but it is not feasible to pay too much attention to this factor. Current practice favors a maximum size of 2½ to 2¾" and a minimum of ½" for a small percentage of the product. The ½" size should not exceed 25% of the total coarse aggregate, which should be well graded between the ½ and 2¾" limits.

Typical aggregate specifications are given on pages 1383 and 1387.

Typical tests of stone are described in Chap. XI (p. 705).

Slag Aggregate.—Crushed blast-furnace slag has been given attention as a substitute for stone and gravel, as in some localities

its use materially cheapens the pavement. There has been considerable doubt as to the effect of slag in combination with cement. The slag-concrete roads which have had service tests, in conjunction with the laboratory, extending over a considerable period indicate that a tough, strong concrete can be constructed of properly selected slag and that this concrete is not weakened by chemical



10-ft. Wide	Cement bbls.	Fine Aggr. Cu. Yds.	Coarse Aggr. Cu. Yds.	Concrete Cu. Yds.	Deformed Metal Joint lbs.	¼" Round Pins lbs.	¾" Round Smooth Bar lbs.	½" Deformed Bar, lbs.
100'	34.78	10.40	18.26	21.60	None	None	333.33	None
1 Mi.	1836.38	549.12	964.13	1140.69	"	"	17599.82	"
1 Sq. Yd.	.313	.094	.164	.194	"	"	3.00	"

16-ft. Wide

100'	55.65	16.64	29.22	34.57	132.94	6.26	333.33	53.44
1 Mi.	2938.32	878.59	1542.82	1825.30	7019.23	330.53	17599.82	2821.63
1 Sq. Yd.	.313	.094	.164	.194	.748	.035	1.875	.301

18-ft. Wide

100'	62.61	18.72	32.87	38.88	132.94	6.26	333.33	53.44
1 Mi.	3305.81	968.42	1735.54	2052.86	7019.23	330.53	17599.82	2821.63
1 Sq. Yd.	.313	.094	.164	.194	.665	.031	1.667	.267

20-ft. Wide

100'	69.57	20.81	36.52	43.20	132.94	6.26	333.33	53.44
1 Mi.	3673.30	1098.77	1928.26	2280.96	7019.23	330.53	17599.82	2821.63
1 Sq. Yd.	.313	.094	.164	.194	.598	.028	1.50	.240

FIG. 160.—Illinois concrete pavements (1922).

action due to the slag aggregate. Road concrete constructed of slag, however, tends to pit on the surface, due to a small percentage of pumice in the aggregate, and this is unslightly at best. Slag-concrete pavement serves the traffic quite satisfactorily, and in certain instances it can be used to advantage, but engineers, as a rule, prefer stone or hard gravel for most conditions of material

(text continued on page 460.)

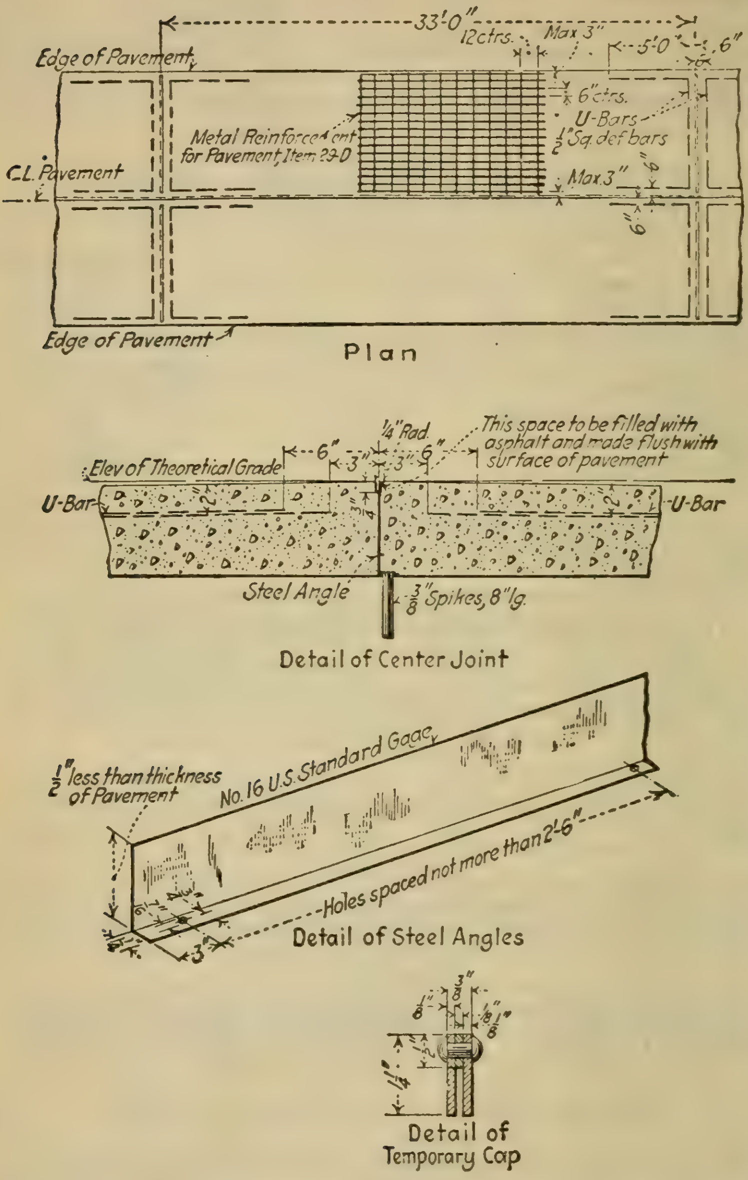


FIG. 161.—New York State standard concrete section (1922) Concrete 7-in. thick for this type of reinforcement.

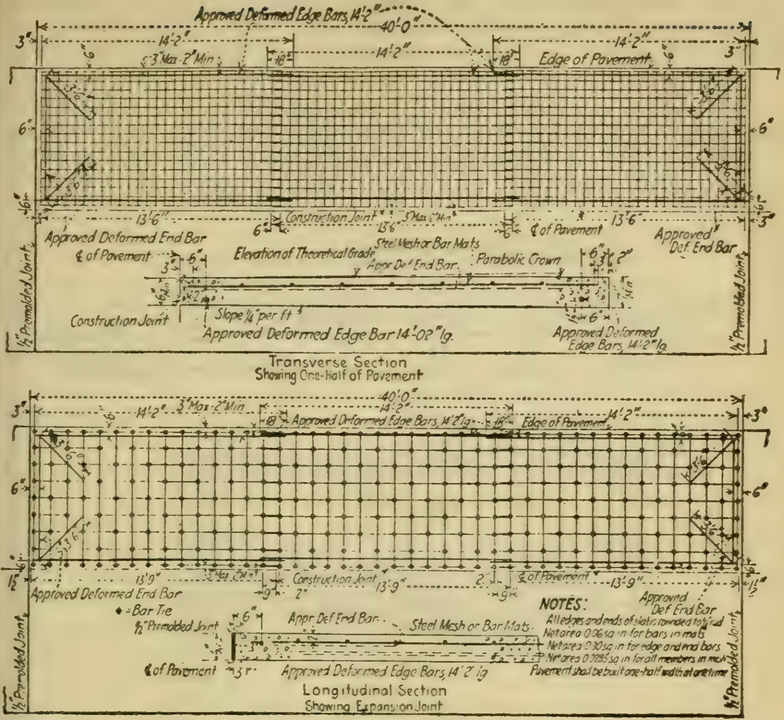


FIG. 162.—New York State (1923 standard) concrete pavement.

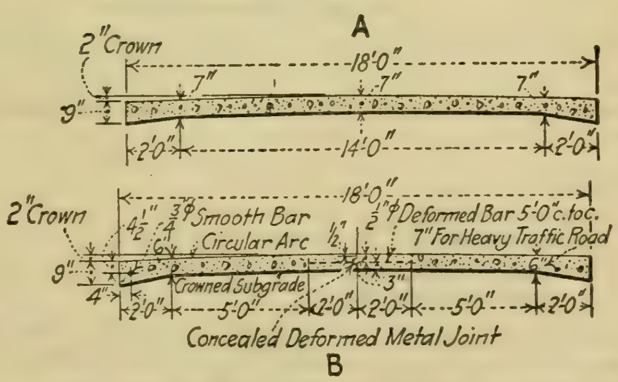


FIG. 163.—State of Illinois 1923 standard.

supply. Slag aggregate is entirely satisfactory for concrete-paving bases. Slag should weigh at least 1800 lb. per cubic yard and have a test of wear of not exceeding 12% (Standard Slag Abrasion Test).

Sand.—The sand used should be a hard, clean, well-graded sand free from organic impurities and containing only a small percentage of loam or silt. A hard, sharp, graded sand which does not pulverize under rolling pressure or water slack is essential.

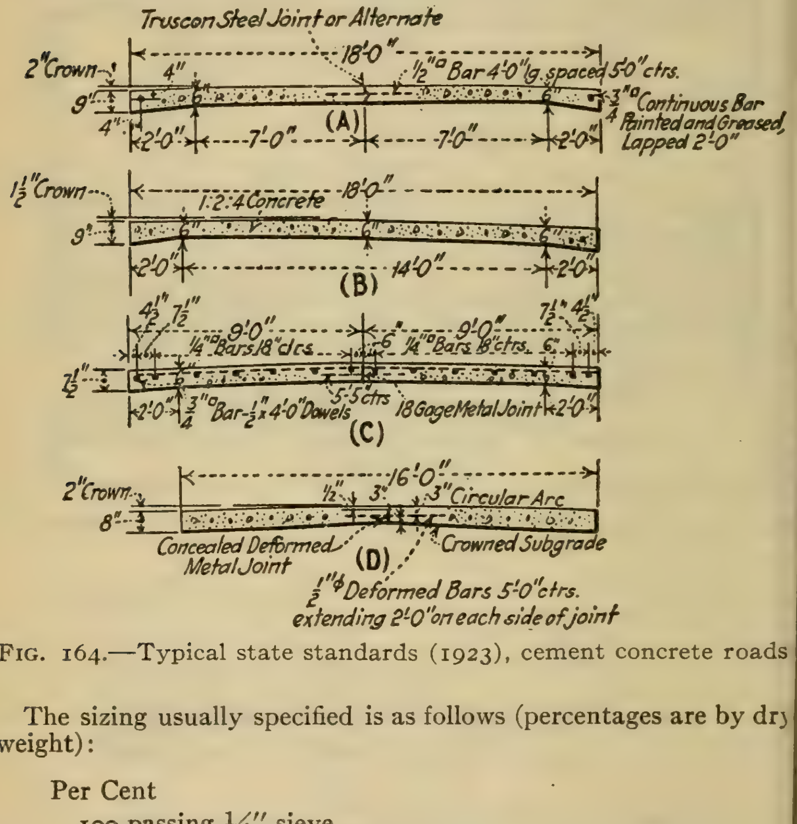


FIG. 164.—Typical state standards (1923), cement concrete roads

The sizing usually specified is as follows (percentages are by dr weight):

Per Cent

100 passing ¼" sieve.
20 minus passing No. 50 sieve.
6 minus passing No. 100 sieve.
5 minus loam and silt.

Sand and cement mixed in the same proportion required for pavement must develop at least as much strength as standard Ottaw sand[1] and cement mixed in the same proportions.

In exceptional cases, rock-crusher dust can be substituted for a part or whole of the natural-sand aggregate, but under the usua

[1] Ottawa sand is furnished by the Ottawa Silica Co. of Ottawa, Ill.; 100 % passes a No. 20 sieve and 100 % is retained on a No. 30 sieve. It has abou 37 % of voids and a fineness modulus of 3.0.

conditions of material supply this expedient should be used with caution (see Specifications, and Sand Tests, Chap. XI).

Water.—Water shall be free from silt and organic matter and shall not show a strong alkaline or acid reaction (see Chap. XI for tests).

Expansion Joints.—The premolded type is the most practicable form for good work; the required properties and tests are given on page 1401.

Joint Plates.—Straight steel or corrugated steel plates Nos. 14 or 16 U. S. gage with flange on the bottom punched for spiking to the grade are as good a form as can be used. Sixteen gage is thin enough (see Figs. 161 and 163). It is believed that the straight plate is superior to the grooved or corrugated form, which tends to increase the liability of spalling.

Amounts of Material Required. *Amount of Water.*—The amount of water required will vary with the natural dampness of the loose aggregate, its sizing, and the cement content of the mix. For the usual 1 : 1½ : 3 concrete having a good workable consistency, the use of from 30 to 40 gal. per cubic yard is about right. Either excessively dry or sloppy concrete is undesirable. Some specifications describe slump tests to determine consistency (see p. 744). Such clauses are undoubtedly desirable in case of dispute, but for ordinary construction operations visual inspection is sufficient. The concrete should be plastic, that is, it should not be so wet that the mortar and stone separate when dumped or so wet that after rolling and finishing free water runs off the surface and drips off the forms. It is desirable for the mortar to flow slightly, as this produces a denser concrete with the usual amount of manipulation obtained under ordinary working conditions. Theoretically, fairly dry concrete is stronger than the plastic mix, but if a mix is so dry that it requires unusual care in spreading, tamping, and spading the actual result day after day is not so satisfactory as where the plastic mix is used.

Sprinkling subgrade takes from ½ to 1½ gal. per square yard for dry sand per square yard of pavement.

Curing concrete takes from 10 to 30 gal. per square yard if properly done, depending on weather conditions and time of year. (For the effect of curing on strength, see page 477.)

The total amount of water, all purposes, will range from 20 to 40 gal. per square yard, ordinary depths of concrete, or from 70 to 150 gal. per cubic yard of concrete.

Slump-test Values.—For defining the limits of allowable consistency in the Specifications, the slump-test definition is probably desirable. The standard test is described in Chap. XI (p. 744). According to Prof. Abrams of Lewis Institute, the following range will produce satisfactory consistency.

Machine finishing methods 1″ to 2″ slump.
Hand finishing methods 3″ to 4″ slump.

Amounts of Sand Stone and Cement.—Table 91 page 466 gives Abrams Quantity tables. Table 207 page 1092 gives other authority in amounts of aggegate. Fullers Rule is given on page 1092.

TABLE 90.—COMPARISON OF STATE HIGHWAY DEPARTMENT SPECIFICATIONS FOR CONCRETE FOUNDATIONS FOR PAVEMENTS WITH SPECIFICATIONS FOR CONCRETE PAVEMENTS COMPILED BY PORTLAND CEMENT ASSOCIATION

January, 1923

State	Date of specifications	Thickness of base	Proportions		Time of mixing in minutes		Fine aggregate					Coarse aggregate				
							Are specifications for base as rigid as for pavement?	Minimum percentage of strength of Ottawa sand in 1 : 3 mortar		Maximum allowable percentage of clay or loam in sand		Are specifications as rigid for base as for pavement?	Allowable per cent of wear for crushed stone		Maximum size in inches	
			Concrete base	Concrete pavement	Concrete base	Concrete pavement		Concrete base	Concrete pavement	Concrete base	Concrete pavement		Concrete base	Concrete pavement	Concrete base	Concrete pavement
Alabama	1920	..	1 : 9 1 : 3 : 6	1 : 2 : 3	1	1	No	75	100	5	3	No	...	5	3	2
Arizona	1922	..	1 : 3 : 6	1 : 2 : 3½	1	1	No	100	100	5	3	No	...	5	2½	2
Colorado	1922	..	1 : 3 : 6	1 : 2 : 3	1½	1½	Yes	100	100	3	3	No	5	4	2½	2
Delaware	1922	..	1 : 2½ : 5	1 : 2 : 4	1	1½	Yes	100	100	3	3	Yes	3⅓	3⅓	2¾	2¾
Florida	1919	..	1 : 3 : 6	Top 1 : 2 : 3	1	1	No	75	100	5	5	No	...	4	3	2
Georgia	1922	..	1 : 3 : 6	1 : 2 : 4	1	1	No	85	100	3	3	No	8	5	2¾	2¾
Illinois	1922	..	1 : 2 : 3½	1 : 2 : 3½	1	1	Yes	100	100	3	3	Yes	7	7	2½	2½
Indiana	1920	..	1 : 3 : 5	1 : 2 : 3	1	1	No	100	100	5	3	No	6	5	2½	2½
Kansas	1922	..	1 : 3 : 5	1 : 2 : 3½	1	1	No	80	100	5	3	No	...	7	3	2
Kentucky	1922	..	1 : 2½ : 5	1 : 2 : 3½	1¼	1¼	Yes	100	100	3	3	Yes	6	6	2½	2½
Maryland	1922	6	1 : 3 : 6	1 : 2 : 4	1	1	No	75	100	5	3	No	5	4	2½	2¾
Michigan	1922	..	1 : 2 : 4	1 : 1½ : 3	1	1	Yes	100	100	3	3	Yes	6	6	2½	2½
Missouri	1919	5	1 : 3 : 5	1 : 2 : 3	1	1	Yes	100	100	3	3	No	5	...	2	1½

Montana	1922	..	1 : 3 : 6	1 : 2 : 3	1	1	Yes	100	100	3	3	Yes	...	...	3	3
Nebraska	1922	..	1 : 3 : 6	1 : 2 : 3	1	1	Yes	100	100	3	3	No	6	4	2	2
New Jersey	1922	..	1 : 3 : 5	1 : 1½ : 3	1¼	1½	Yes	100	100	4	4	Yes	3½	3½	3	3
North Carolina	1922	..	1 : 2½ : 5	1 : 1½ : 3	1½	1½	Yes	100	100	3	3	No	5	4	2¾	2¾
Ohio	1922	..	1 : 2½ : 5	1 : 1½ : 3	1	1	No	85	100	5	3	No	8	6	2½	2½
Oklahoma	1921	5	1 : 3 : 6	1 : 2 : 3	1	1½	No	75	100	5	3	No	6	6	2	2
Oregon	1922	..	1 : 3 : 6	1 : 2 : 3	1	1	No	90	100	4	2	No	5	4	3	3
Pennsylvania	1922	..	1 : 2½ : 5	1 : 2 : 3	1¼	1¼	No	90	100	5	3	No	5	5	2¾	2¾
South Dakota	1920	..	1 : 3 : 6	1 : 2 : 3	1	1	No	75	100	5	3	No	...	5	3	2½
Utah	1922	..	1 : 3 : 6	1 : 2 : 3	1	1	No	90	100	5	3	Yes	5	5	3	2
Virginia	1920	..	1 : 3 : 6	1 : 2 : 4	1	1	No	85	100	5	3	No	8	5	2	2
West Virginia	1921	..	1 : 2½ : 5	1 : 2 : 2½	1	1	No	75	100	3	3	Yes	6	6	3	3
Wisconsin	1922	5	1 : 2½ : 5	1 : 2 : 4	1	1	Yes	100	100	3	3	Yes	6	6	2	2

NOTES.—Undated specifications listed with the date they were received from highway departments. Per cent wear listed is for crushed stone. Some specifications permit the use of pebbles or slag with lower per cent of wear, especially in the base. Specifications were not available for the states omitted.

Factors of Design.—The main factors of design are richness of mix, reinforcement, and joint details. Manipulation methods covering time of mix, care in curing, joints, etc., are discussed under Specifications page 1470, Inspection Details page 1299, to on page 1313.

Richness of Mix.—Richness of mix affects beam strength, resistance of the pavement surface to abrasion, and the imperviousness of the surface, seepage, and disintegration due to frost action. Road concretes in ordinary use (1926) range from 1:2:4 to 1:1½:3 mix with cement contents of from 1.6 to 2.1 bbl. per cubic yard of concrete.

While beam strength is slightly increased by added richness of mix, this factor has very little weight in the final decision, as there is no well-defined advantage of greater unit strength and less depth. The decision in regard to mix rests on its effect on abrasion and the porosity of the concrete, that is, richness above 1:2½:5 is entirely dependent on the production of a longer surface life before the pavement needs recapping. On this basis of reasoning, it is certainly not desirable to increase the cost over that required for 1:2½:5 mix by more than 10 to 15 cts. per square yard for each additional year of surface life. A mix of 1:2½:5 (1.25 bbl. of cement per cubic yard) taking traffic directly is not satisfactory or economical under moderate traffic, and even where such a surface is given a light protective coat of oil and screenings it rarely lasts over 3 to 5 years before a surface of asphaltic concrete or standard block is necessary. A considerable mileage of 1:2:4 concrete pavements (1.6 to 1.7 bbl. of cement per cubic yard) has demonstrated its ability to withstand moderate traffic up to 3000 rubber-tired vehicles daily (10-hr. count in summer) for a reasonable term of years (6 to 12) before recapping is desirable. The increased cost of this mix over and above the 1:2½:5 mix is most certainly justified as it amounts to approximately 0.1 bbl. per square yard or, in money, about 30 cts. per square yard initial cost, and probably adds at least 5 years to its surface life. In actual practice under the usual inspection and batching procedure, considerable variation of mix will occur, which produces occasional areas of concrete which are not true 1:2:4 mix. There have been enough failures of small areas, apparently due to porosity using this mix, to warrant a slight increase in richness to offset construction imperfections on even moderate-traffic roads, and on heavy-traffic roads a 1:1½:3 mix is apparently justified to increase density to withstand traffic pounding. The average life of such pavements cannot yet be set and will vary greatly due to different traffic and excellence of construction, but they seem to be about as expensive a mix as is desirable. A cement content of over 1.9 bbl. per cubic yard is of doubtful value and seems a waste of money except possibly on village pavements. This is not a needless caution, as the cement factor has been steadily rising, and while from the standpoint of the material industries it is desirable to sell all the cement possible it is poor engineering to use a needless amount. The latest expedient is to call a sack of cement 0.95 cu. ft. in place of 1.0 cu. ft. thus raising the cement factor about 5%.

Tentative conclusions in regard to richness of mix may be expressed as follows:

For light- and moderate-traffic roads up to 3000 vehicles daily a mix of approximately 1 : 1¾ : 3½ with an average cement content of not to exceed 1.7 bbl. per cubic yard ought to give satisfactory results, provided the batching scheme prevents individual batches varying more than 7% from the average. (This is a reasonable limit of variation under modern specifications.) This mix should show a 28-day-age compressive strength of from 2500 to 3500 lb. per square inch.

For the heavier-traffic roads (3000 to 6000 vehicles daily) a mix of approximately 1 : 1½ : 3 with a cement content of not to exceed 1.9 ought to give satisfactory results and appears to be economically justified. This mix should show tests of 3000 to 4000 lb. at 28 days.

Table 91 page 466 shows Abrams' proportions for 3000-lb. concrete; it is an excellent general guide, but, considering the wide range in aggregate sizes as delivered, it is impracticable to cut the proportioning too fine. For explanation of fineness-modulus method of proportioning mix, see page 478.

Reinforcement and Joints.—The use of steel in concrete pavements is a comparatively recent development. Figures 154 to 164 show the different methods in use at present (1926). The wide variation in type, location, and function of the steel as used indicates conclusively that there is no certain knowledge as to the exact value of reinforcement in pavement design.

It is conceded that the use of some steel is practically and economically justified for equalizing construction imperfections in the concrete, for preventing interior cracks from spreading apart, for strengthening corners for cantilever load stresses and shear, and possibly for helping to keep adjacent slabs at the same elevation and to distribute wheel loads across joints. There is, however, considerable doubt as to the wisdom of the use of the amount of steel shown in some recent designs. Central areas of slabs are indeterminate in design, as there is no way of telling how they are stressed under the fluctuating conditions of traffic loads and subgrade support. It is uneconomical to attempt to increase the slab strength of central areas by the use of steel as a true reinforcement.

The design of depth for a pavement where reinforcement is used differs from that of plain concrete. The assumptions for the design of plain concrete slabs are quite rational and definite, namely, the greatest stress is produced by a live load at the extreme corner of a slab; if the slab is designed of uniform strength throughout and made strong enough to resist corner failure, the pavement should serve well, even though internal cracks occur, and the elimination of such cracks is not of much importance, except on the ground of appearance. These assumptions, however, require the use of a needless amount of concrete in internal areas where cracks do not develop. If internal cracks can be eliminated or reduced to an infrequent occurrence, it is evident that the use of steel at corners tends to produce a slab of more uniform resistance and makes it possible to reduce the required thickness of concrete. From an economic standpoint it is therefore desirable to use some steel for

(text continued on page 469.)

TABLE 91.—ABRAMS' TABLE OF PROPORTIONS AND QUANTITIES FOR 1 CU. YD. OF CONCRETE

(Based upon laboratory investigations, using approved materials, compressive strength, 28 days, with workable plasticity, 6 by 12″ cylinders, 3000 lb. per square inch)

Size		Fine aggregates, screen per inch														
Coarse aggregate, inches	Cement in barrels aggregates in cubic yards	0–28			0–14			0–8			0–4			0–⅜″		
		Cement	Fine	Coarse	Cement	Fine	Coarse	Cement	Fine	Coarse	Cement	Fine	Coarse	Cement	Fine	Coarse
No. 4 screen to ¾	Proportions	1.0	1.3	2.4	1.0	1.6	2.4	1.0	1.8	2.3	1.0	2.0	2.3	1.0	2.7	1.5
	Quantities	1.96	0.37	0.69	1.85	0.44	0.66	1.82	0.48	0.62	1.75	0.52	0.59	1.79	0.72	0.40
No. 4 screen to 1	Proportions	1.0	1.3	2.7	1.0	1.6	2.6	1.0	1.8	2.6	1.0	2.0	2.5	1.0	2.6	1.8
	Quantities	1.90	0.36	0.76	1.77	0.42	0.68	1.72	0.46	0.66	1.67	0.50	0.62	1.72	0.66	0.46
No. 4 screen to 1½	Proportions	1.0	1.2	3.1	1.0	1.6	3.2	1.0	1.7	3.1	1.0	2.0	3.0	1.0	2.4	2.4
	Quantities	1.82	0.32	0.84	1.68	0.40	0.79	1.63	0.41	0.75	0.61	0.47	0.72	1.62	0.57	0.57
No. 4 screen to 2	Proportions	1.0	1.2	3.5	1.0	1.5	3.5	1.0	1.6	3.7	1.0	1.9	3.6	1.0	2.2	3.1
	Quantities	1.75	0.31	0.90	1.63	0.36	0.85	1.55	0.36	0.85	1.52	0.43	0.81	1.53	0.50	0.70
No. 4 screen to 2½	Proportions	1.0	1.1	3.8	1.0	1.4	3.9	1.0	1.6	4.0	1.0	1.8	4.0	1.0	2.1	3.5
	Quantities	1.72	0.28	0.97	1.58	0.33	0.91	1.51	0.35	0.89	1.49	0.40	0.88	1.50	0.46	0.78
No. 4 screen to 3	Proportions	1.0	1.1	3.9	1.0	1.4	4.1	1.0	1.5	4.1	1.0	1.7	4.1	1.0	2.0	3.7
	Quantities	1.69	0.28	0.97	1.58	0.33	0.97	1.49	0.33	0.90	1.49	0.37	0.90	1.49	0.44	0.81
⅜ to ¾	Proportions	1.0	1.3	2.3	1.0	1.7	2.3	1.0	1.9	2.3	1.0	2.2	2.2	1.0	2.8	1.4
	Quantities	1.96	0.37	0.67	1.85	0.46	0.63	1.82	0.51	0.62	1.75	0.57	0.57	1.79	0.75	0.37
⅜ to 1	Proportions	1.0	1.3	2.6	1.0	1.7	2.6	1.0	1.9	2.5	1.0	2.2	2.4	1.0	2.7	1.7
	Quantities	[illegible]	0.36	0.74	1.77	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]

3/8 to 1½	Proportions	1.0	1.3	3.0	1.0	1.7	3.0	1.0	1.9	3.0	1.0	2.1	2.9	1.0	2.0	2.2
	Quantities	1.82	0.35	0.80	1.68	0.43	0.75	1.63	0.46	0.73	1.61	0.50	0.68	1.62	0.63	0.53
3/8 to 2	Proportions	1.0	1.3	3.3	1.0	1.7	3.4	1.0	1.8	3.5	1.0	2.0	3.4	1.0	2.4	2.9
	Quantities	1.75	0.34	0.86	1.63	0.41	0.83	1.55	0.42	0.80	1.52	0.45	0.77	1.53	0.62	0.66
3/8 to 2½	Proportions	1.0	1.3	3.7	1.0	1.6	3.7	1.0	1.7	3.9	1.0	2.0	3.8	1.0	2.3	3.3
	Quantities	1.72	0.33	0.95	1.58	0.37	0.87	1.51	0.37	0.87	1.49	0.44	0.84	0.50	1.51	0.74
3/8 to 3	Proportions	1.0	1.2	3.8	1.0	1.6	3.9	1.0	1.7	4.0	1.0	1.9	4.0	1.0	2.2	3.5
	Quantities	1.68	0.30	0.95	1.58	0.37	0.91	1.49	0.37	0.88	1.49	0.42	0.88	1.49	0.48	0.77
½ to ¾	Proportions	1.0	1.5	2.3	1.0	1.9	2.2	1.0	2.1	2.2	1.0	2.3	2.1	1.0	2.8	1.3
	Quantities	1.96	0.44	0.67	1.85	0.52	0.61	1.82	0.56	0.59	1.75	0.59	0.54	1.79	0.75	0.34
½ to 1	Proportions	1.0	1.5	2.5	1.0	1.9	2.5	1.0	2.1	2.4	1.0	2.3	2.4	1.0	2.8	1.6
	Quanities	1.90	0.42	0.70	1.77	0.50	0.66	1.72	0.53	0.61	1.67	0.57	0.59	1.72	0.72	0.41
½ to 1½	Proportions	1.0	1.4	2.8	1.0	1.9	2.9	1.0	2.1	2.9	1.0	2.2	2.8	1.0	2.7	2.1
	Quantities	1.82	0.37	0.75	1.68	0.47	0.73	1.63	0.51	0.69	1.61	0.52	0.66	1.62	0.65	0.51
½ to 2	Proportions	1.0	1.4	3.3	1.0	1.9	3.3	1.0	2.0	3.4	1.0	2.2	3.3	1.0	2.7	2.7
	Quantities	1.75	0.36	0.86	1.63	0.46	0.79	1.55	0.46	0.78	1.52	0.50	0.74	1.53	0.62	0.62
½ to 2½	Proportions	1.0	1.4	3.6	1.0	1.8	3.6	1.0	1.9	3.7	1.0	2.1	3.7	1.0	2.6	3.1
	Quantities	1.72	0.35	0.91	1.58	0.43	0.85	1.51	0.42	0.83	1.49	0.46	0.81	1.50	0.57	0.69
½ to 3	Proportions	1.0	1.3	3.7	1.0	1.8	3.8	1.0	1.8	3.9	1.0	2.1	4.	1.0	2.4	3.3
	Quantities	1.68	0.33	0.92	1.58	0.42	0.89	1.49	0.40	0.86	1.49	0.46	0.88	1.49	0.53	0.63
¾ to 1	Proportions	1.0	1.7	2.4	1.0	2.1	2.4	1.0	2.4	2.1	1.0	2.6	2.2	1.0	3.1	1.5
	Quantities	1.90	0.48	0.68	1.77	0.55	0.63	1.72	0.61	0.53	1.67	0.64	0.55	1.72	0.79	0.39
¾ to 1½	Proportions	1.0	1.7	2.7	1.0	2.0	2.8	1.0	2.3	2.7	1.0	2.5	2.7	1.0	3.0	2.0
	Quantities	1.82	0.46	0.73	1.79	0.50	0.70	1.63	0.55	0.65	1.61	0.59	0.64	1.62	0.73	0.48
¾ to 2	Proportions	1.0	1.7	3.1	1.0	2.0	3.1	1.0	2.3	3.1	1.0	2.5	3.0	1.0	3.0	2.4
	Quantities	1.75	0.44	0.80	1.63	0.48	0.75	1.55	0.53	0.72	1.52	0.56	0.67	1.53	0.68	0.55
¾ to 2½	Proportions	1.0	1.7	3.3	1.0	2.0	3.5	1.0	2.3	3.4	1.0	2.4	3.4	1.0	2.9	2.8
	Quantities	1.72	0.43	0.84	1.63	0.47	0.83	1.51	0.52	0.76	1.49	0.53	0.75	1.50	0.64	0.62

TABLE 91.—ABRAMS' TABLE OF PROPORTIONS AND QUANTITIES FOR 1 CU. YD. OF CONCRETE—(*Continued*)
(Based upon laboratory investigations, using approved materials, compressive strength, 28 days, with workable plasticity, 6 by 12″ cylinders, 3000 lb. per square inch)

Size		Fine aggregates, screen per inch														
Coarse aggregate, inches	Cement in barrels aggregates in cubic yards	0–28			0–14			0–8			0–4			0–⅜″		
		Cement	Fine	Coarse	Cement	Fine	Coarse	Cement	Fine	Coarse	Cement	Fine	Coarse	Cement	Fine	Coarse
¾ to 3	Proportions	1.0	1.7	3.5	1.0	2.0	3.7	1.0	2.3	3.7	1.0	2.4	3.6	1.0	2.8	3.1
	Quantities	1.68	0.43	0.88	1.58	0.47	0.87	1.49	0.51	0.81	1.49	0.53	0.79	1.49	0.62	0.68
1 to 1½	Proportions	1.0	1.7	2.8	1.0	2.0	2.9	1.0	2.3	2.7	1.0	2.6	2.6	1.0	3.1	2.0
	Quantities	1.82	0.46	0.75	1.68	0.50	0.73	1.63	0.55	0.65	1.61	0.62	0.62	1.62	0.75	0.48
1 to 2	Proportions	1.0	1.5	3.2	1.0	1.9	3.5	1.0	2.2	3.3	1.0	2.4	3.3	1.0	3.0	2.6
	Quantities	1.75	0.39	0.83	1.63	0.46	0.85	1.58	0.51	0.76	1.52	0.54	0.74	1.53	0.68	0.59
1 to 2½	Proportions	1.0	1.4	3.4	1.0	1.9	3.8	1.0	2.0	3.7	1.0	2.3	3.7	1.0	2.7	3.1
	Quantities	1.72	0.35	0.86	1.58	0.45	0.89	1.51	0.44	0.83	1.49	0.51	0.81	1.50	0.59	0.69
1 to 3	Proportions	1.0	1.3	3.6	1.0	1.8	4.0	1.0	2.0	3.9	1.0	2.2	3.9	1.0	2.7	3.3
	Quantities	1.67	0.33	0.90	1.58	0.42	0.94	1.49	0.44	0.86	1.49	0.48	0.86	1.49	0.59	0.73

increasing corner strength. The rational and sure use of steel at corners with thinner concrete depends on the control of internal cracking.

The successful use of steel requires the subdivision of the pavement into slabs of such size that their integrity can usually be preserved under the action of traffic and frost. It is undesirable to reduce the size of slab below the maximum feasible size, as additional joints introduce additional corners, which are points of weakness, and more wear occurs at joints from spalling, etc. A small-sized slab also tends to rock under eccentric loading.

The decision in regard to spacing of contraction, expansion, and longitudinal joints should reduce internal cracking to negligible frequency. If transverse joints are provided at intervals of about 30 to 35′ and longitudinal joints are provided for each 8 to 10′ of pavement width, experience shows that controlled cracks are being provided for which correspond with the natural cracking tendency of concrete under frost and traffic action; that is, the adoption of this system of joints generally eliminates frequent internal cracks, provided the pavement has sufficient depth to handle traffic loads. This system of subdivided slabs with depths of 7 to 8″ of concrete will practically eliminate internal cracks, and if the corners are reinforced enough to prevent corner cracks for these depths, a fairly rational design results. This can be secured by corner reinforcement (see page 400). It is undesirable to reduce the thickness below the depths shown in Table 86. The proper use of corner reinforcement and tie bars around the slabs apparently justifies a reduction in the average thickness of the concrete of about 1 to 1½″ under that required for a plain concrete slab.

This saving justifies a maximum expenditure of about 4.5 cts. per square foot (1922 costs) for steel, or about 1.0 to 1.5 lb. of steel per square foot.[1] This amount is not often necessary or advisable. The use of approximately 0.5 to 0.8 lb. per square foot apparently gives a rational and economical result for most cases, and this amount is most certainly a good investment, considering pavement cost.

The use of steel in pavements may be briefly summarized as follows: Figures 154 to 157 show typical systems of reinforcement which appear logical.

Mesh and Bar Types of Reinforcement.—The mesh type having small unit members and close spacing is probably more effective than bars for equalizing construction imperfections, temperature, and moisture stresses. It can be placed closer to the surface of the pavement with less probability of chipping of the concrete than bar reinforcement. Theoretically, it has very little effect as a true tension reinforcement but its use seems beneficial in reducing longitudinal cracks in wide slabs. It is particularly useful on wide street pavements where it seems undesirable on account of appearance to divide the pavement into narrow strips.

[1] Mesh is an expensive form of reinforcement and should be used only on the heaviest type of pavement.

The bar type is better to hold adjacent slabs in contact after a crack occurs, and bars can be more scientifically arranged to give the most effective result where an effort is made to use steel as a true tension reinforcement. Bars, however, must be placed farther below the surface (at least 2″), and they are not very effective as a true tension reinforcement where the pavement depth is less than 7 to 8″. Bars can be most effectively used as a corner reinforcement and as ties around the outer edges of the slabs. Where used as ties, they are effective for any depth that may be adopted.

Where the bars are used, they are generally assembled into mats and tied together to insure proper spacing and elevation in the concrete. Theoretically, this may be desirable, but it requires additional isolated tie bars which have very little practical value. Personally, the author has never experienced any difficulty in placing bars by hand sufficiently close to their proper location, provided the reinforcement is all in the same horizontal plane. The man placing the steel must be intelligent, but his wage is more than offset by the saving in the labor of manufacturing the mats and in the saving of unnecessary tie bars.

The typical recommended sections (Figs. 154 to 157) assume that the bars are placed by hand and not wired. If it is desired to use the mat form, add tie bars at the longitudinal laps.

Corner Reinforcement.—Figure 135 (p. 401) shows graphically the effect of different percentages of steel on modulus of rupture; as discussed on page 398, it is probably not desirable to raise the design tension value above 65% of the modulus of rupture for 28-day concrete.

There are two formulas that can be considered in approximating the amount of reinforcement in corners. These, derived on page 415, are as follows:

$$d = \sqrt{\frac{2.6W}{S}} \qquad S = \frac{2.6W}{d^2} \tag{1}$$

$$d = \sqrt{\frac{2W}{S}} \qquad S = \frac{2W}{d^2} \tag{2}$$

Formula (1) is adopted for plain concrete and assumes approximately 85% of the wheel load carried by the corner. Formula (2) assumes approximately 66% of the wheel load carried by the corner. Formula (2) assumes the use of doweled or grooved joints to help transmit the load across the joint. Formula (1) is on the safe side, and as there is considerable doubt as to the practical effectiveness and desirability of doweled joints, it seems the more rational formula to use. For an 8″ depth of 1 : 1½ : 3 concrete pavement on a main road in states having a statutory limitation of 28,000-lb. gross vehicle load, the design wheel load plus impact is approximately 14,000 lb. and the value of S becomes

$$S = \frac{2.6(14{,}000)}{8^2} = 580 \text{ lb.}$$

A design tension value of 580 lb. requires at least one-fourth to three-tenths of 1% reinforcement. The corner reinforcement shown in Fig. 154 is based on this assumption.

In a similar manner Table 92 is constructed. It is intended merely as a rough guide, as the final decision rests on cut-and-try methods under actual traffic tests.

TABLE 92.—APPROXIMATE PERCENTAGE OF CORNER REINFORCEMENT

Depth of pavement, inches	Design wheel load *W*, in pounds, including impact allowance		
	8,000	14,000	20,000
6	0.3	Not suitable	Not suitable
7	0.0	0.4	Not suitable
8	0.0	0.25	0.5
9	0.0	0.0	0.35

TABLE 93.—AREA OF STEEL IN SQUARE INCHES PER FOOT WIDTH OF SLAB (CORNER REINFORCEMENT)

Depth of pavement, inches	Design wheel load *W*		
	8,000	14,000	20,000
6	0.22	....	....
7	....	0.34	....
8	....	0.24	0.48
9	....	....	0.38

Most corner cracks occur at a distance of less than 2½′ from the corner, so that if corner reinforcement with the effective area given in these tables is provided for a distance of 2.5′ back from the corner it is apparently a safe design. The recommended reinforcement layout of Fig. 154 is based on this assumption. A convenient size for corner reinforcement bars is ⅜ or ½″.

Side Bars.—The use of some kind of tie around the outer edges of the slabs is quite uniformly approved. Bars are effective in reducing spread of cracks which may develop. They increase the distribution of load across internal cracks by holding the parts in close contact and by dowel action. They should be strong enough to resist wheel-load shear after the crack forms. They have practically no effect in increasing strength or in the prevention of the formation of cracks. Convenient sizes in general use are ½ to ⅝″ bars (see Figs. 159, 160, and 164).

Dowels.—The advocates of the use of dowel-pin connections between adjacent slabs believe that such construction (see Fig. 159, p. 456) keeps adjacent slabs at the same elevation and reduces the

load carried by the slab corner. The sizes and spacing in ordinary use are shown in Fig. 160; the dowels are coated with bitumen or wrapped in paper or encased in pipe to permit movement at transverse joints. There is comparatively little trouble in the matter of equal level of adjacent slabs where the joints are smooth and vertical. The few cases which occur due to defective construction can be easily remedied. Personally, the author does not favor the attempt to produce a 50% distribution across construction transverse joints by means of dowel connections.[1] It is doubtful if pin or groove joints can be constructed which permit contraction and expansion and yet are still very effective in permanently transmitting load. It is believed that it is a better general principle of design to make the corners self-supporting by means of corner reinforcement, the action of which is reasonably sure.

The recommended designs Figs. 154 to 157 are based on this principle of design.

Joint Details.—It is desirable to reduce the number of joints to a minimum, as they are generally the weak points in construction; they also tend to spall due to rub and traffic pounding. Also, enough joints must be used to permit a rational use of steel. Less spall, however, occurs at well-defined joints with rounded edges and a complete smooth separation of adjacent blocks than at natural contraction cracks or where the submerged type of joint is used.

The treatment of expansion and contraction is the source of very wide disagreement among engineers.

Expansion.—Some very excellent practice ignores expansion on the ground that the stress produced is well under the working stress of concrete in compression and that it is cheaper to repair infrequent blow-ups due to expansion than to spend the necessary money for expansion joints. (Expansion joints cost about 8 to 12 cts. per linear foot of joint and their use increases the pavement cost about 2½ to 4 cts. per square yard.) Personally, the author believes that all joints should be both expansion and contraction joints and that it is not wise to omit them.

Expansion produces a stress of approximately 13 lb. per degree of temperature where no movement occurs, and produces an elongation of free end slabs of approximately 0.008″ per 100′ of road per degree of temperature. For the extreme range of temperature in northern climates, expansion probably does not produce a compressive stress of over 1000 lb. per square inch where expansion joints are not used. This stress will not cause failure of the concrete but is sufficient to cause buckling or blow-ups under certain conditions. Expansion joints permit the free expansion of the individual slabs and prevent internal stresses. The space to be provided depends on the range of temperature expected; for northern climates with a maximum of perhaps 80° above the temperature of construction an allowance of approximately ¾″ per 100′ is necessary and 1″ per 100′ is not excessive. Where joints are placed every

[1] Tie bars at internal cracks are effective in producing distribution across such cracks, as no expansion or contraction need be provided at these points where the road is constructed with transverse joints every 33′.

;3′, a joint thickness of ⅜″ is a good allowance; this corresponds vith ordinary practice. Such joints are of the premolded type. t is essential that they be constructed in a vertical plane to revent rising of slabs along the joint due to expansion pressure. t is also essential that a complete separation of slabs is obtained; hat is, the bitumen must extend from bottom to top of the pavement and from edge to edge.

It is not difficult to keep these joints vertical on level grades, rovided reasonable care is exercised as described in the specifications. On grades of 4% or more, however, it is advisable to back hem up on the downhill side with 16-gage steel plates as shown in ig. 161.

Transverse Contraction Joints.—While it seems advisable to make ll transverse joints combined expansion and contraction joints paced about 33′, there is considerable tendency to increase the istance between expansion joints to 100 to 300′ and to provide itermediate submerged contraction joints at intervals of 30 to 70′. uch joints are generally 14- or 16-gage steel plates cut one-half ich less depth than the pavement. The concrete is screeded and nished continuously over these joints and contraction produces a ore or less jagged crack over the top of the plate which tends to pall more under traffic than the rounded-edge expansion joint; ie argument for these joints is based on a smooth-riding pavement, ut there seems to be no well-defined basis of fact in this contention; these steel plates cost about the same as a ⅜″ premolded joint.

Longitudinal Joints.—There are two general types: the submerged steel plate where the entire width of pavement is conructed at one time (see Fig. 161, p. 458), and the plane of separation int where the pavement is constructed in successive strips. The cond is the better method, as a better line and a denser edge are cured. With the submerged joint the concrete along the center eel is often porous, due to lack of care in manipulation; this ondition cannot be observed and remedied as well as where the ivement is constructed in successive strips. In the second ethod a denser edge is insured, as when the forms are stripped it easy to detect and correct carelessness in spading along the edge. is important to get a denser impervious concrete along these ints, as water is bound to seep in and the concrete is subjected to greatest strain at this location.

Design Details.—Design details consider depth, width, crown, id detail arrangement of joints and reinforcement.

Depth.—The design of depth was discussed on pages 392 to 428 mmarized in Table 86 (p. 426).

Width.—Concrete pavements on rural roads range from 9 to 20′ width. Single-track 9′ pavements are of doubtful value, for if a ad has enough traffic to warrant the concrete type of pavement is certainly warrants greater width. These single-track concrete ads have not been at all satisfactory in localities with which the thor is familiar. Widths of 18 or 20′ seem the most logical for nditions which make concrete suitable on rural highways. Extra dth on curves was discussed in Chap. 3 and the results summarized on page 132. Current practice in this matter is indicated

in Fig. 21 (p. 129). The widths of village streets are discussed on page 165. Alleys in business districts should be at least 18′ wide; in resident sections at least 16′.

Crown.—There are two popular shapes of crown curve, parabolic and circular. The parabolic is easier to figure, and for narrow rural pavements of 18′ or less in width which can be struck off by a single templet there is no objection to this type of curve. For wider pavements, particularly for street work, the circular arc is probably better, as a single templet can be used for the successive strips without danger of inequalities in the crown. Street *crowns* made up of a curved central portion and inclined-plane sides are to be avoided, as, while this is an easy form to construct, it does not look well, as it gives the appearance of a sag in the crown. The circular-arc crown is probably better adapted to all conditions.

The difference in elevation between the center line of the pavement and the edge of gutter line varies with width and grade The adopted height of crown depends on convenience for traffic and appearance. On rural highways, for widths up to 20′, usual practice ranges between ⅛″ per foot of half width to ¼″ per foot. A total crown of 2″ for 16, 18, or 20′ total width of pavement serves very well. This requires a crown radius of from 200 to 250′.

On wider pavements and village streets the range in standard practice is shown in Figs. 167*A* to 167*B* (p. 505). Superelevation and shoulder and ditch grading were discussed in Chap. 3 page 124. Standard practice is indicated by Fig. 309 (p. 956).

In alley work a crown slope towards the center of ¼″ per foot is satisfactory. Alleys generally drain toward and along the center line with pick-up catch basins at short intervals.

Detail Arrangement of Reinforcement and Joints.—See Figs. 154 to 164 (pp. 451 to 460).

Steep Grades.—See pages 425 and 101 for limitations imposed by steep grades.

Specifications.—See Part III (p. 1470 to 1474).

Construction Equipment.—See (p. 1312 to 1263).

Inspection Details.—See Chap. XVI (p. 1299 to 1264).

General Maintenance Methods.—Detail maintenance is discussed in Chap. VII, (pp. 565 to 569). Concrete-pavement maintenance consists in the repair and sealing of cracks and joints, the replacement of disintegrated areas, and the renewal of shoulders. Cracks and joints are sealed with bitumen or a mixture of bitumen and sand. Disintegrated areas are either temporarily resurfaced with cold-patch bituminous mixtures or dug out and replaced with concrete, generally using a quick-setting cement (see Maintenance p. 565) to avoid long inconveniences to traffic. On lighter-traveled roads shoulders are renewed by scraping additional earth up along the edge of the pavement with a road scraper; on heavily traveled roads shoulders are built up solid along the edge by the use of gravel-oiled or cold-patch macadam.

RECENT CONCRETE DATA

At various places in the text reference is made to the effect of time of mixing on strength; care in curing on strength and fineness

nodulus on strength. The following data briefed from publica-ions of the Portland Cement Association gives the most recent lata (1923) based on experiments at Lewis Institute under the lirection of Prof. Duff Abrams.

Very often both contractor and inspector are somewhat skeptical is to the necessity for the more recent specification clauses based on ational care in aggregate sizing, time of mixing and care in curing. Even a casual inspection of the experimental results here recorded ought to convince any unbiased inspector of the necessity of care n these particulars.

Proper Time of Mixing Increases Strength.—Effective mixing nvolves both time and number of revolutions. Many inspectors and contractors believe that the number of revolutions controls trength of mix and that by speeding up the mixer the time can be

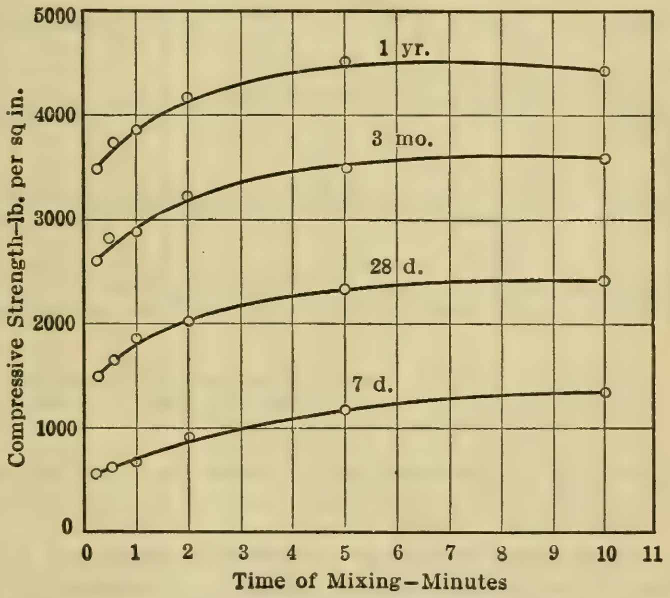


FIG. 1.—Relation between time of mixing and the compressive strength of concrete.

educed without any detriment to the mix. Figures 1 and 2 how that the specification clauses involving both time and speed re essential clauses and that both must be complied with for the est results.

Proper Curing Increases Strength of Concrete.—Careful dis-nction should be made between the requirements of concrete for ater during the mixing operation and in curing. A safe rule to ollow is to use the smallest quantity of *mixing* water that will roduce a sufficiently plastic mixture for the work in hand, and then give the surface of the concrete as much *curing* water as possible fter the concrete is placed.

Concrete hardens because of chemical reactions between Portland cement and water. Down to an amount less than can be used in construction work, the smaller the quantity of mixing water the stronger will be the concrete. Therefore, the quantity of mixing water should be reduced as far as possible. However, once the concrete is placed, and it has hardened, conditions change and ample curing water should be provided.

The chemical reactions of the hardening of concrete are slow, and if sufficient moisture is not present they cannot be completed. The mixing water essential to proper hardening of freshly placed concrete is often lost by absorption or evaporation even after the

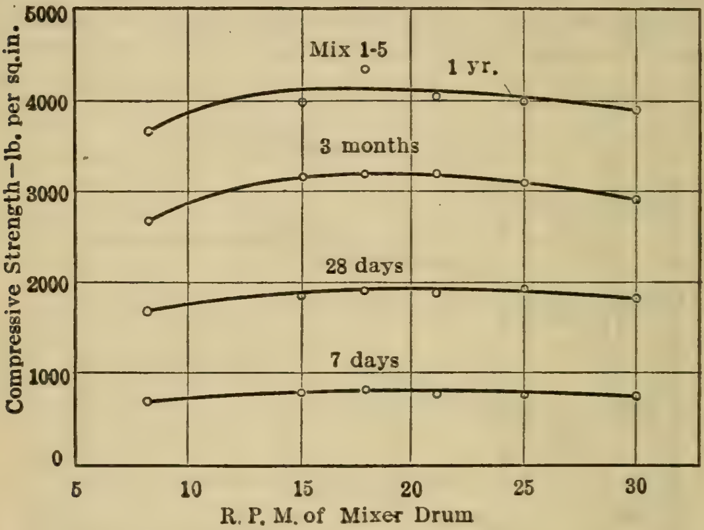


FIG. 2.—Relation between speed of mixer and the compressive strength of concrete

concrete has begun to harden. Under such conditions, concrete attains only part of its potential strength. Therefore, the water content of freshly placed concrete should be conserved. Keeping concrete damp during its early hardening period, or, in other words providing plenty of curing water, prevents evaporation of necessary moisture, and permits concrete to harden under favorable conditions.

Protect Concrete While Hardening.—Tests show that protection during the early hardening period greatly increases the strength and resistance to wear of concrete. Figure 3 gives a summary of the results of these tests. All specimens were tested at the same age—4 months. One set was allowed to harden in air for the full 4 months the second set was stored in damp sand for 3 days and in air for the remaining 117 days; the third set was stored in damp sand 21 days and in air the remaining 99 days; while the fourth set was stored in damp sand the full 120 days and was tested while still damp

'hus the increased strength and resistance to wear was caused olely by the better curing conditions provided.

Note that keeping concrete damp for the first 10 days increased s compressive strength 75%, for 3 weeks 115%, and for 4 months 45%.

Note also that keeping concrete damp for the first 10 days ecreased the amount of wear 40%, and for 3 weeks 55%. Keep-ng concrete damp for 4 months did not cause a further decrease in 'ear, but the specimens were tested damp. Had they been allowed › dry out for a few days before being tested, the amount of wear ould probably have been less.

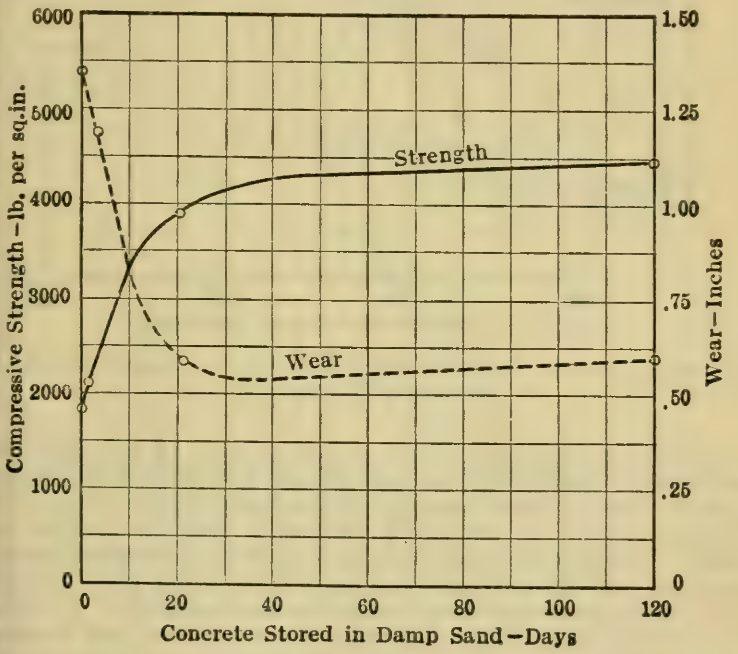


FIG. 3.—Keeping concrete damp the first ten days adds 75% its compressive strength. It reduces the amount of wear 40% *vice versa,* increases the resistance to wear 65%. Three ek's protection adds still more strength and hardness.

Reversing the form of these wear results, 10 days protection reased the resistance to wear of concrete 65% and 3 weeks otection 120%. Thus proper curing increases the resistance to ar of concrete almost in the same proportion as the compressive ength. Needless to say, resistance to wear is an important isideration in floors, pavements and platforms.

Careful Grading of Aggregate Increases Strength of Concrete.[1] rtland cement, which forms only 15 to 25% of the volume of icrete, is carefully tested to see that it meets exacting specifica-ns. Aggregates, which form 75 to 85% of the volume of

[1] Quoted from Pamphlet of Portland Cement Association.

concrete, should also be tested. Aggregates should be clean, free from coatings or organic impurities and structurally sound. Furthermore, proper size and grading of aggregates, or proper proportioning of fine and coarse aggregates, may double the strength of concrete, as shown in Fig. 4. Doubling the strength as the results of a few hours' study and a little closer supervision is surely worth while.

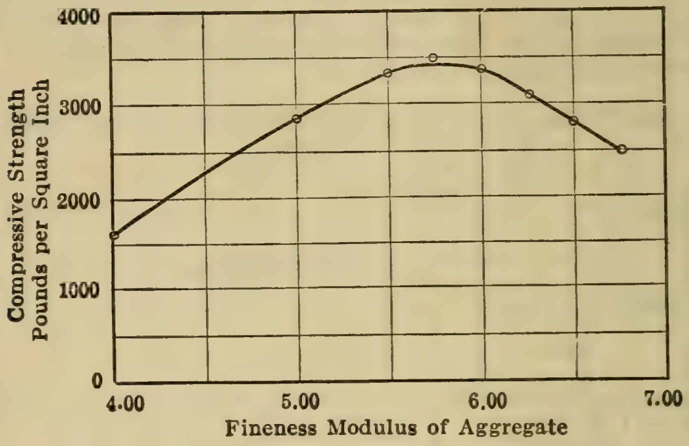


FIG. 4.—Relation between the grading af the aggregate and the strength of concrete.

Grading of Aggregates Varies.—Any number of fine and coarse aggregates of widely different size and gradings may meet the usual specifications in those respects. If combined in arbitrary proportions, such as 1:2:4, some of them will make far better concrete than others. For best results a proportion should be determined for each case that will fit the particular aggregates to be used. A little study will quickly show which of two or more available aggregates is the better graded and will therefore make the best concrete. Consideration of these factors may permit the use of local material with a saving in freight. It may also result in securing high-grade concrete at lower cost. Such studies can readily be made by an competent engineer or inspector, and at very small expense.

Assuming a given consistency, which should always be as stiff as the nature of the work permits, and a given mix (proportion of cement to total volume of mixed aggregate), the strength of the resulting concrete depends on the size and grading of the aggregate. In general, the larger and coarser the aggregate, the stronger will be the concrete. Coarse sand will produce stronger concrete than fine sand, while stone or pebbles in which the larger sizes predominate will produce stronger concrete than smaller stone or pebbles.

Fineness Modulus Shows Grading.—A simple index number, called the "fineness modulus," has been developed to indicate the size and grading of aggregates, and therefore their value for use

oncrete. It can be applied to either fine or coarse aggregates, or o any combination of them. It shows at a glance which of two or nore aggregates is the better graded. From it the proportions in vhich given fine and coarse aggregates should be combined are asily computed.

To determine the fineness modulus of an aggregate it is only ecessary to make a simple sieve analysis. A set of U. S. standard quare mesh sieves is used, each sieve having a clear opening double he width of the next smaller size. These sizes are 100, 50, 30, 16, and 4 meshes per linear inch, and 3/8-in., 3/4-in. and 1½-in. or larger aggregates 3-in. and 6-in. sieves may also be used. The ercentage of the aggregate, either by weight or by volume, coarser han each sieve is measured. The sum of these percentages, divided y 100, is called the fineness modulus. A close approximation can e obtained by using only alternate sieve sizes, 50, 16, 4 and 3/4, and stimating the percentages for the others. These four sieves make convenient set for field use.

Table 2, on p. 479, gives the sieve analyses and fineness moduli of en aggregates. The first is sand, the second, pebbles. The other

TABLE 2.—SIEVE ANALYSIS AND FINENESS MODULUS OF AGGREGATE

Ref. No.	Sieve analysis. Per cent coarser than each sieve									Fineness modulus	Comp. strength of a 1:4 mix. lb. per sq. in.
	100	50	30	16	8	4	3/8	3/4	1½		
1	99	93	63	40	20	0	Sand	..	..	3.15	
2	...	Pebbles		..	..	100	75	25	0	7.00	
3	99	93	68	55	39	23	17	6	0	4.00	1630
4	99	95	79	70	59	49	37	12	0	5.00	2910
5	100	95	84	77	70	62	46	16	0	5.50	3370
6	100	97	86	79	73	68	51	21	0	5.75	3540
7	100	98	90	85	79	74	56	18	0	6.00	3390
8	100	98	91	89	85	81	61	20	0	6.25	3150
9	100	99	94	93	90	87	65	22	0	6.50	2790
10	100	100	98	96	94	93	70	24	0	6.75	2540

ght aggregates were formed by combining these materials in rious proportions. As the percentage of pebbles increases, the gregate becomes coarser and the fineness modulus grows larger, us reflecting the size and grading of the aggregate.

Good Grading Doubles the Strength.—The last column shows the mpressive strength of concrete made from those eight gregates in the proportions of one volume of cement to four lumes of total aggregate. These strengths are plotted in Fig. 4. ote that up to a certain point, the concrete increases in strength the aggregate gets coarser. Beyond that point the aggregate too coarse for the amount of cement used and the concrete creases in strength. Note also that proper grading of aggregate ay double the strength of the concrete. For other mixes the me principle holds true, although the greatest strength would be

obtained with a different grading. The richer the mix, the coarser the aggregate and the larger the fineness modulus that will give the strongest concrete.

Aggregate No. 3, with a fineness modulus of 4.00, corresponds to a bank run gravel; it contains entirely too much fine material for best results. Aggregate No. 10, with a fineness modulus of 6.75, corresponds in grading to a crusher run stone; it contains too much coarse material. This shows the folly of using either bank run gravel or crusher run stone. Such material should always be screened and recombined in proper proportions.

Fineness Modulus is Simple.—The fineness modulus of any mix- of two or more aggregates, such as fine and coarse, is merely the weighted average of the fineness moduli of the separate materials. For example, if 32% of sand No. 1 (*F. M.* = 3.15) is mixed with 68% of pebbles No. 2 (*F. M.* = 7.00), the fineness modulus of the mixture is:

$$F.\,M. = \frac{32 \times 3,15 + 68 \times 7.00}{100} = 5.77$$

This agrees closely with the value given in the table (5.75) fo aggregates No. 6, which was found by a sieve analysis.

Sieve analyses, which are easily made, will give the fineness modul of any fine and coarse aggregates, while a simple calculation wil show the fineness modulus of any mixture of them.

If the proper fineness modulus for the work in hand is known (pag 482), the proportions in which given fine and coarse aggregate

TABLE 3.—STRENGTH OF CONCRETE FROM AGGREGATES O UNIFORM FINENESS MODULUS

Mix 1:4 by volume. Relative consistency 1.10. Age at test 2 days. Specimens (6 by 12″ cylinders) were stored in damp sand and tested damp

Ref. No.	Sieve analysis. Per cent coarser than each sieve									Fineness modulus	Comp. strength lb. per sq. in.
	100	50	30	16	8	4	3/8	3/4	1½		
11	95	89	82	75	67	67	67	62	0	6.04	2780
12	98	95	90	83	83	83	50	22	0	6.04	2530
13	98	94	90	86	83	80	55	18	0	6.04	2590
14	96	90	80	80	80	80	60	38	0	6.04	2570
15	90	85	81	78	75	73	66	56	0	6.04	2580
16	100	93	82	73	73	73	63	47	0	6.04	2880
17	100	100	100	92	81	60	45	26	0	6.04	2930
18	100	99	96	91	80	50	50	38	0	6.04	3040
19	99	98	90	85	80	76	38	38	0	6.04	3030
20	99	98	91	85	80	76	67	8	0	6.04	2690
Average											2760
Maximum value											3040
Minimum value											2530
Mean variation from average											6.2%

must be combined to secure that fineness modulus can readily be computed.

Sieve analyses of aggregates may vary over a wide range, but as long as the sum of the percentages coarser than each sieve (fineness modulus) is the same, the aggregates may be expected to give uniform results in concrete. This relation is shown in Table 3, which gives the sieve analyses, fineness moduli and concrete strengths of 10 aggregates made up by artificial grading of the same sand and pebbles. Although the sieve analyses vary, the total, or fineness modulus, is the same in all cases. Note that all 10 aggregates made concrete of substantially the same strength, the mean variation from the average being only 6.2%.

Thus the fineness modulus, which is an index of the size and grading, indicates the value of an aggregate for use in concrete. The reason is that, eliminating variations in the absorption of the aggregates, the fineness modulus reflects the quantity of mixing

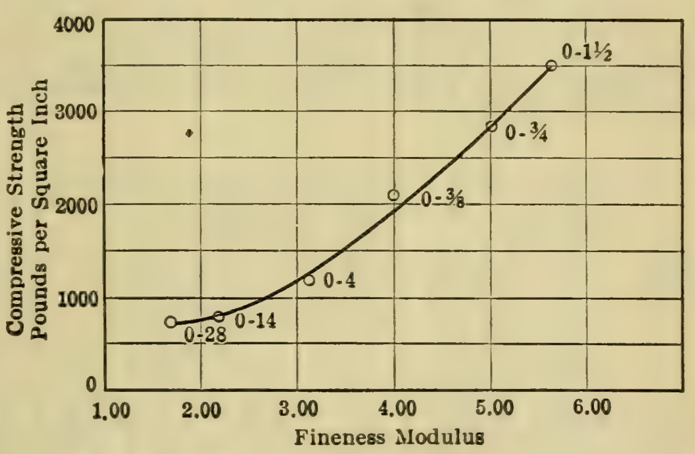


FIG. 5.—Relation between maximum size of aggregate, fineness modulus and strength of concrete.

water necessary to obtain a given consistency. In general, consistency and mix being the same, the fineness modulus indicates the strength that can be expected in the concrete. Other conditions being the same, aggregates having the same fineness modulus will produce concrete of substantially the same strength.

Proportions Depend on Aggregates.—Applying this principle to actual construction, it means that if several fine and coarse aggregates are available, concrete of substantially the same strength can be made from any combination of fine and coarse material, provided that the materials are proportioned to have the same fineness modulus. For one set of material the proper proportions may be 1:2.3:2.7, for another 1:1.6:3.4 and so on. To apply an arbitrary mixture, such as 1:2:3 to all aggregates, regardless of their grading, will not give uniform or satisfactory results. The mixture should be determined after a study of the particular aggregates to be used.

If the grading of the aggregate changes during the progress of the work it is an easy matter to change the mixture accordingly.

It is obvious that aggregates having a larger maximum size will have a larger fineness modulus. This is shown in Fig. 5. Note that as the maximum size increases, the fineness modulus increases, and also that the strength of concrete increases.

As stated before, larger fineness moduli can be used with rich mixes than with lean ones. Therefore, the best value of fineness modulus will depend on both the mix and the maximum size of the aggregate. Table 4, below, indicates the best value of the fineness modulus for the usual mixes and sizes of aggregates. The closer the aggregate comes to meeting these values the stronger will be the concrete.

These values for fineness modulus are based on sand and pebble aggregate for ordinary reinforced concrete. If crushed stone, slag or flat pebbles are used as coarse aggregate, or stone screenings as fine aggregate, reduce the values by 0.25. For mass work the values can be increased by 0.10 for ¾″ aggregates, 0.20 for 1½″ aggregate, and 0.30 for 3″ aggregate. *Fine aggregate used in concrete should not have a higher fineness modulus than that given for mortars of the same mix.*

TABLE 4.—BEST VALUES FOR FINENESS MODULUS

Mix cement—aggregate	Mortar	Size of aggregates					
	0–4	0–⅜ In	0–¾ In	0–1 In.[1]	0–1½ In.	0–2 In.	0–3 In.
1:7	3.20	3.95	4.75	5.15	5.55	5.95	6.40
1:6	3.30	4.05	4.85	5.25	5.65	6.05	6.50
1:5	3.45	4.20	5.00	5.40	5.80	6.20	6.60
1:4	3.60	4.40	5.20	5.60	6.00	6.40	6.85
1:3	3.90	4.70	5.50	5.90	6.30	6.70	7.15
1:2	4.20	5.05	5.90	6.30	6.70	7.10	7.55
1:1	4.75	5.60	6.50	6.90	7.35	7.75	8.20

[1] Considered as "half size" sieves; not used in computing fineness modulus.

Shrinkage of Aggregates after Mixing.—Table 4 gives the true mix, *viz.*, the proportion between the volume of cement (expressed as unity) and the volume of total aggregate after the fine and coarse have been combined. In the nominal mix, which is the one ordinarily used, the volumes of fine and coarse aggregates are given separately, *i. e.*, 1:2:4 or 1:½:3. The nominal mix can readily be converted into the true mix. *Vice versa*, if the ratio between fine and coarse aggregate is known, the true mix can be quickly converted into the nominal mix. For the usual ratios of fine and coarse aggregate (fine aggregate being 20 to 70% of the total) the volume of total aggregate after mixing will be about seven-eighths of the sum of the volumes of fine and coarse aggregate measured separately. For example, aggregate No. 6 in Table 2 contained 32% sand. Four cubic feet of the total aggregate

would require 4.57 cu. ft. ($4.00 \times 8/7$) of fine and coarse aggregate measured separately. Of that 4.57 cu. ft., 32% or 1.46 cu. ft. would be sand and 68% or 3.11 cu. ft. would be pebbles. A 1:4 true mix would be obtained by using 1:1.46:3.11 nominal mix. Because of this shrinkage when fine and coarse aggregate are combined a 1:2:4 nominal mix does not correspond to a 1:6 true mix as sometimes assumed, but to about 1:5.2 true mix.

More accurate values for the shrinkage of mixed materials can be obtained by measuring the volume of mixed aggregate obtained by mixing fine and coarse aggregates in the proper proportions, or by calculation from the weights of unit volumes of fine, coarse and mixed aggregates. For most cases, however, the average shrinkage of one-eighth is sufficiently reliable.

Example 1.—Four fine aggregates and three coarse aggregates are available for a certain job. Which should be used? Their sieve analyses give the following data:

Aggregate	Per cent coarser than each sieve									Fineness modulus	Range in size, in.
	100	50	30	16	8	4	3/8	3/4	1½		
Sand. . . . . . No. 1	100	90	70	55	35	20	0	0	0	3.70	0–3/8
Sand. . . . . . No. 2	100	85	65	40	20	0	0	0	0	3.10	0–4
Sand. . . . . . No. 3	95	75	60	30	0	0	0	0	0	2.60	0–8
Screenings . No. 4	85	80	75	35	25	0	0	0	0	3.00	0–4
Stone. . . . . . No. 5	100	100	100	100	100	100	100	40	0	7.40	3/8–1½
Pebbles. . . . No. 6	100	100	100	100	100	100	70	30	0	7.00	4–1½
Pebbles. . . . No. 7	100	100	100	100	100	100	45	15	0	6.60	4–1

Because of better size and grading (larger fineness moduli) sand No. 1 and stone No. 5 are the best materials. Sand No. 2 and pebbles No. 6 are good materials, but sand No. 3 is quite fine and pebbles No. 7 are rather small. Screenings No. 4 are well graded, but an equally well graded sand would be preferable, because rounded particles find their way into place with less mixing water. That is the reason why a higher fineness modulus is permissible when sand is used than when screenings are used (see text preceding Table 4). Therefore the other materials would be better. Any of these materials will make good concrete, however, provided the fine and coarse materials are proportioned to secure a combined fineness modulus suitable to the mix and maximum size of the aggregate.

Example 2.—A 1:4 true mix and a 1½″ maximum size of aggregate have been adopted. Sand No. 2 and pebbles No. 6 have been selected because their cost is less than that of the other materials. In what proportions should they be combined to get the best results? Or, in other words, what nominal mix should be used?

The proper value of the fineness modulus for these conditions is 5.00 (see Table 4). Then sand No. 2 and pebbles No. 6 must be combined in such proportions as to secure a fineness modulus of

6.00 for the total aggregate. Let P equal the percentage of sand and $100 - P$ the percentage of pebbles.

$$\begin{aligned} P \times 3.10 + (1.00 - P) \times 7.00 &= 6.00 \\ 3.10P + 7.00 - 7.00P &= 6.00 \\ 3.9P &= 1.00 \\ P &= 0.26 \text{ or } 26\% \end{aligned}$$

Thus of the total volume of aggregate, 26% should be sand and 74% pebbles. The true mix being 1:4 the sum of the volumes of sand and pebbles for a one bag batch measured separately will be 4.57 cu. ft. ($4 \times \frac{8}{7}$). Of this, 26% or 1.19 cu. ft. will be sand and 74% or 3.38 cu. ft. will be pebbles. The nominal mix will then be 1:1.2:3.4.

Example 3.—During the progress of the work it becomes necessary to substitute screenings No. 4 and stone No. 5. What change should be made in the nominal mix?

When screenings are used as fine aggregates or when crushed stone is used as coarse, the values for the total fineness modulus given in Table 4 should be reduced by 0.25. In this case screenings and crushed stone are both being used and the value of 6.00 for the fineness modulus used in Example 2 should therefore be reduced by 0.50, or to 5.50. Using the same notation as before:

$$\begin{aligned} P \times 3.00 + (1.00 - P) \times 7.40 &= 5.50 \\ 3.0P + 7.4 - 7.4P &= 5.50 \\ 4.4P &= 1.9 \\ P = 0.43 &= 43\% \end{aligned}$$

Dividing the total volume of aggregate before mixing (4.57 cu. ft.), 43% fine and 57% coarse, the new proportions are found to be 1:2.0:2.6.

AUTHOR'S NOTE.—The student should bear in mind that while the fineness modulus method is a valuable laboratory method for preliminary investigations it is not as practicable a method for specifying construction practice as the nominal mix regulated by maximum and minimum sizes and proportions of the sand and coarse aggregates.

The usual specification is based on proportions of mortar and coarse aggregate which give good practical results and the strength of these mixes as affected by fineness modulus is controlled by stipulating maximum and minimum percentages passing certain screens. See specifications page 1386 for sands; page 1384 for coarse aggregates.

INCREASED STRENGTH FROM RICHER MIXES

Tests clearly bring out the increase in strength resulting from the use of richer mixes. Typical results are given in the following table. The same aggregate, with a fineness modulus of 5.75 and graded up to 1½″ in size, was used in all tests. The cement was a mixture of equal parts of four brands purchased on the Chicago

market. The relative consistency of all specimens was the same, 1.10, with a slump of 3 to 4″. This consistency is suitable for most construction work. All tests were made at the age of 28 days. Thus the increase in strength was due solely to increases in the quantity of cement.

Ordinary concrete mixes (1 : 3½ : 7 to 1 : 1½ : 2) contain from 3 to 8 sacks of cement per cubic yard of concrete. Note that within this range the strength of concrete increases in direct proportion to the quantity of cement. Each additional sack of cement per cubic yard adds about 500 pounds per square inch to the strength of concrete.

EFFECT OF QUANTITY OF CEMENT ON THE STRENGTH OF CONCRETE

True mix[1]	Approximate nominal mix[1]	Sacks of cement per cubic yard of concrete	Compressive strength, lbs. per square inch
Neat	....	29.7[2]	6630
1:⅓	....	23.0	5720
1:1	1: ⅜: ¾	15.7	5070
1:2	1: ¾: 1½	10.5	4070
1:3	1:1½: 2	7.9	3570
1:4	1:1½: 3	6.3	2760
1:5	1:2 : 3½	5.2	2090
1:7	1:3 : 5	3.9	1400
1:9	1:3½: 7	3.1	1030
1:15	1:6 :12	1.8	440

[1] The true mix is the ratio between the volume of cement, expressed as unity, and the volume of total aggregate after the fine and coarse have been combined. In the nominal mix, which is the one ordinarily used, the volumes of fine and coarse aggregate are expressed separately. The nominal mix can readily be converted into the true mix because for the usual proportions of fine and coarse aggregate (fine aggregate 20 to 70 % of the total) the volume of combined aggregate after mixing is about seven-eighths of the sum of the volumes of fine and coarse aggregate measured separately. Because of this shrinkage a 1:3:5 nominal mix does not give a 1:8 true mix as sometimes assumed, but about a 1:7 true mix.

[2] The volume of concrete obtained from neat cement depends on the quantity of mixing water used. For water-cement ratios between 0.3 and 0.6. the volume of concrete obtained from one sack (one cubic foot) of dry cement equals 0.5 of a cubic foot plus the amount of water used. In the example given here the water-cement ratio was 0.4 and the shrinkage was therefore about 10 %.

QUICK-HARDENING CONCRETE[1]

"Concrete work is usually allowed to stand many days before it is used. Quite often, however, *time* is the important consideration with new or repair work. The owner wanting early use of his improvement is not willing to wait the usual length of time and it is not necessary for him to do so. He can, with Universal Portland cement, secure in 3 days, concrete as strong as that ordinarily obtained in 28 days.

"High-early-strength concrete is particularly desirable on many jobs, such as special foundations and repair work that must be placed in use within a few days, sidewalks and street work where traffic demands that the improvement be placed in service at the earliest possible time, and frequently in

[1] Quoted from a pamphlet of the Universal Cement Co.

winter where it is desirable to get sufficient strength *quickly* to resist damage by freezing.

"**Simple Methods Accomplish the Result.**—To obtain this high-strength concrete in a few days, all that is necessary is to proportion, mix, place, and protect the concrete in the manner that actual construction experience and thousands of laboratory tests extending over a period of more than 5 years have demonstrated give the desired results. For example, a concrete pavement was built with Universal cement at the Chicago (Buffington, Ind.) plant of the Universal Portland Cement Co. which was opened to traffic when only 2 days old. This pavement has been carrying the heaviest loaded cement trucks for months without any damage to the concrete.[1]

"Simply *decreasing* the amount of water used in mixing greatly increases the 3-day strength of the concrete. Other factors also contribute toward giving a 3-day strength that exceeds the ordinary 28-day strength. The simple factors to obtain this quick-hardening, strong concrete are:

"1. Decreasing the amount of mixing water.
"2. Increasing the mixing time up to 5 min.
"3. Increasing the amount of cement.
"4. Placing the concrete at a temperature of at least 70°F.
"5. Keeping concrete at a temperature of 70°F. for 3 days.
"6. Keeping concrete damp for 3 days.
"7. Using calcium chloride where tests show it increases the strength.

"A good concrete such as is commonly used in building construction work is proportioned 1 sack of cement to 2½ cu. ft. of good sand and 4 cu. ft. of crushed stone or gravel, graded in size from ¼ up to 1½" material. If to the dry materials 7.7 gal. of water are added and the mixing time is 1 min., a concrete will be produced with the strength at different ages, shown in line A of the following table:

	Mix	Gallons water per sack cement	Minutes mixing time	Compressive strengths, pounds per square inch			
				1 day	3 days	7 days	28 days
A	1:2½:4	7.7	1	240	750	1320	2600
B	1:2½:4	7.7	5	340	910	1550	3030
C	1:2½:4	6.1	1	520	1350	2090	3700
D	1:1½:2½	5.5	1	560	1580	2530	4230
E	1:1½:2½	4.4	1	880	2410	3630	5250
F	1:1½:2½	4.4	5	1150	2860	4020	5740
G	1:1½:2½	5.5 (2 % $CaCl_2$)	1	1110	2090	3000	4470
H	1:1½:2½	3.4 (2 % $CaCl_2$)	5	1910	3380	4200	5260
*	1:1¼:2½	4.6	5	1580[a]			

[a] Concrete used at Chicago plant of Universal Portland Cement Co.

"**Quadrupling the 3-day Strength.**—Note that concrete A has 240-lb. compressive strength per square inch at 1 day, 750 lb. at 3 days, 1320 lb. at 7 days, and 2600 lb. at 28 days. But *quick-hardening* concrete with *higher strength* than concrete A in 3 *days* is wanted. Concrete B in the table is the same in every respect as concrete A, except that the mixing time was 5 min. instead of 1 min. This *one* change produced an increase in 1-day strength of 100 lb., or 42 %. By reducing the volume of the mixing water from 7.7 to 6.1 gal. per sack of cement, concrete C is obtained with 1-min. mixing, and with 5-min. mixing the concrete would be still better and stronger. The effect of increasing the amount of cement is shown by concrete D in the table. This is a 1:1½:2½ mix instead of a 1:2½:4 mix as in concrete A. The workability or consistency of concrete D is exactly the same as is A, the mixing time is the same, but D has an increased amount of cement—about 2.1 bbl. per cubic yard as compared with about 1.4 bbl. for A. There is, however, a great increase in the strength at all periods. Decrease the volume of mixing water, making a somewhat drier mixture, and concrete E is the result. Mixtures rich in cement and with the minimum amount of mixing

[1] See table on p. 486 for strength of this concrete.

water require a maximum amount of mixing. Increase the mixing time for concrete E to 5 instead of 1 min., and strengths as in concrete F are obtained.

"Compare strengths at different periods of concretes F and A. Note that by simply increasing mixing time, decreasing volume of mixing water, and increasing quantity of cement, concrete F is obtained with a strength at 3 *days* that is *higher* than concrete A at 28 *days*.

"**Use of Calcium Chloride.**—Still higher-strength concrete at 1 and 3 days, such as concrete G, can be made by adding 2 lb. of calcium chloride per sack of cement. By further reducing the volume of mixing water, increasing the mixing time, and adding calcium chloride, concrete H with the strengths shown is obtained.

"With some cements little or nothing is gained in the way of increased 1- and 3-day strength by adding calcium chloride, while with some there is a marked increase in strength, as shown in the table. Tests should be made with particular materials to determine the effect of using calcium chloride in the mix. If the tests show that calcium chloride produces the desired increase in strength in 1 to 3 days, use it; if not, do not use it.

"The best way to use calcium chloride in the field is to add 100 lb. of commercial calcium chloride to 50 gal. of water in a barrel, stir until the calcium chloride is thoroughly dissolved and a standard solution with 2 lb. of calcium chloride to a gallon of water is obtained. Replace 1 gal. of mixing water *per sack of cement* in a batch of concrete with this standard solution and the right amount of calcium chloride is used.

"The results shown in the table are for concretes placed and maintained at a temperature of at least 70°F. for the time indicated. Increasing the temperature of the mix and the temperature during the curing of the concrete, and at the same time keeping the concrete damp, will give still greater strengths than are shown in the table. The use of steam at a few pounds' boiler pressure for curing will also greatly accelerate the rate of hardening of concrete and increase the 1- and 3-day strengths. Steam is available and may be used to advantage in many places and on many jobs.

"**Advantage in Cold Weather.**—High-early-strength concrete is particularly desirable during the fall and winter months, as such concrete has sufficient strength to resist being damaged by freezing much earlier than concrete proportioned, mixed, placed, and handled in the ordinary manner. This high-early-strength concrete also requires protection from freezing for a shorter period, which is desirable from the cost standpoint.

"**Strong Concrete in 3 Days.**—This quick-hardening concrete giving high strength in 3 *days* is easily obtained with Universal cement by applying the simple methods that have been demonstrated in thousands of laboratory tests made over a period of more than 5 years and used in actual construction practice. If quick-hardening concrete with high 1- and 3-day strengths is wanted, take advantage of *all* of the factors that contribute to making such concrete. These factors are:

"1. *Dry mixtures*. Use the *minimum* amount of mixing water.

"2. *Thorough mixing*. Never less than 1 min. and still better by additional time up to 5 min.

"3. *Rich mixtures*, which means an increased amount of cement. (Concrete A in the table on page 486 has 1.4 bbl., while the much stronger concrete F has 2.1 bbl. cement per cubic yard.)

"4. *Placing concrete* at a *temperature* of at least 70°F.

"5. *Maintaining* concrete at temperature of not less than 70° for the days indicated.

"6. *Curing*. Keeping concrete *damp* for the days indicated.

"7. Use of *calcium chloride* where tests show it gives an increased strength."

ELEMENTS AFFECTING CONCRETE CONSTRUCTION

Chart Presentation of Various Factors Given California Highways

BY C. S. POPE

Construction Engineer, California Highway Department

The following charts have been prepared for use of resident engineers and others with a view to predicting results which may be expected on different phases of concrete construction.

The data have been assembled from various sources which seem dependable but principal reliance has been placed on material available at this time from our own laboratory.

In common with all such generalizations, individual cases, due to the very numerous causes which may affect the results of tests of concrete materials may be expected from time to time to show results at considerable variance wit the findings of these charts.

Application of common sense and discrimination in their interpretation, however, will enable engineers to recognize the influence of these various factors and will make the charts of great value to those who have occasion to use them, and who properly interpret the data furnished by them.

Chart A.—This chart gives compressive strengths of sand and mortars of various proportions. The strengths are given in percentages of comprehensive strength of neat cement. A cement having a compressive strength, neat, of 12,000 lb. per square inch at 28 days is assumed as 100 per cent and all values given are prorated on the basis of the use of this cement in the varying proportions required.

The strength ratio shown assumes a sand which is structurally sound. A sand which is structurally weak will show higher strength ratios with a cement having a low neat strength than with a cement having a high neat

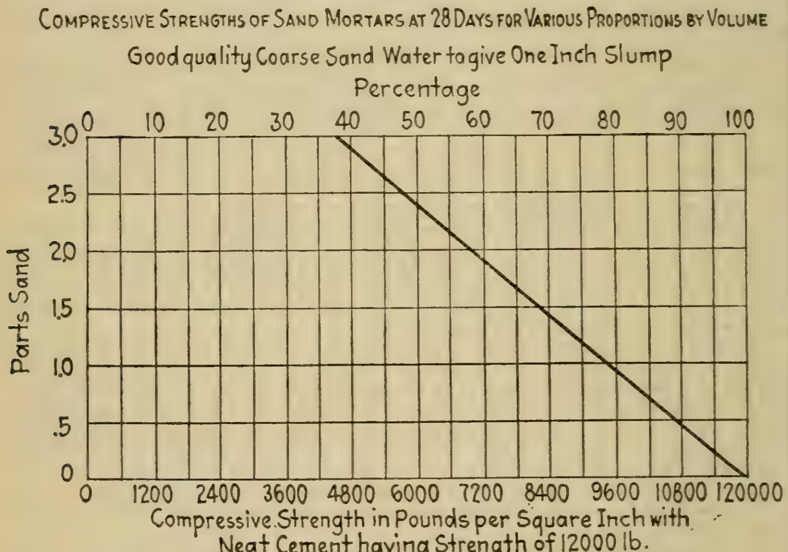


CHART *A*.

strength. The stronger cement brings out the weakness of the sand and the strength ratio for such a material would not be a straight line in the graph shown.

Sixty per cent is probably a conservative figure to use in estimating the probable strength of field concrete based on mortar strengths, the ratio of sand to cement in both concrete and mortar being the same.

Chart B.—This chart shows compressive strength of concrete with varying cement content. The compressive strength is shown in pounds per square inch based on first-class aggregate, and cement testing neat at 12,000 lb. per square inch at 28 days. The concrete is asssumed to have a ½-to-1-in. slump the water varying slightly as required by its aggregate.

Chart C.—This chart shows the effect of voids in coarse aggregate on compressive strength. The graph is particularly valuable and is shown both in percentages and in pounds per square inch. The effect of excess voids in the coarse aggregate is, of course, to require the addition of more sand to maintain workability with a corresponding decrease in compressive strength of the concrete.

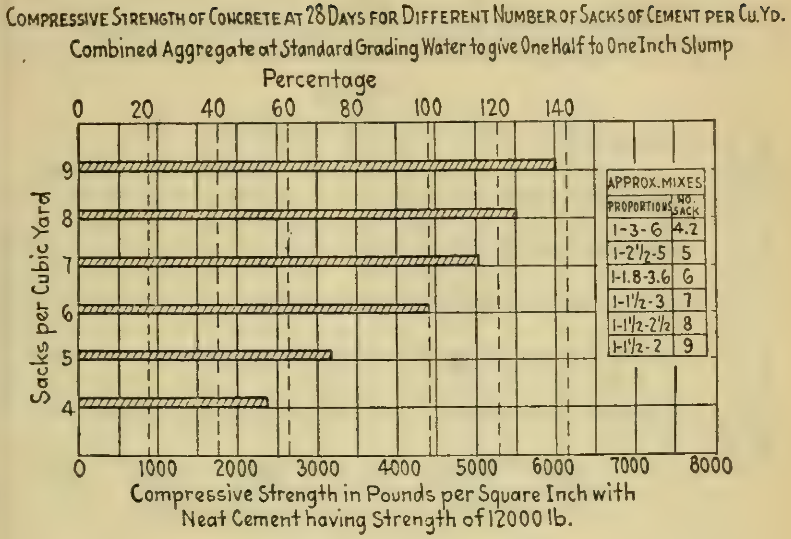


CHART *B*.

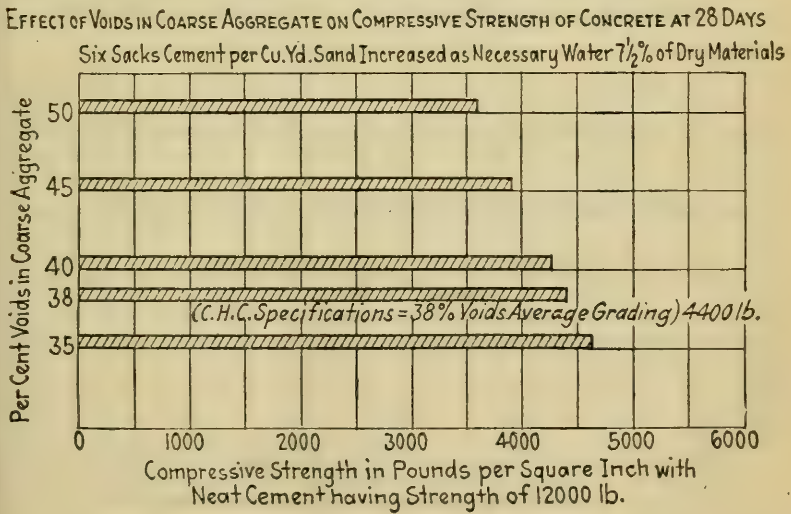


CHART *C*.

Water cement ratio is ratio of volume of water to volume of cement.

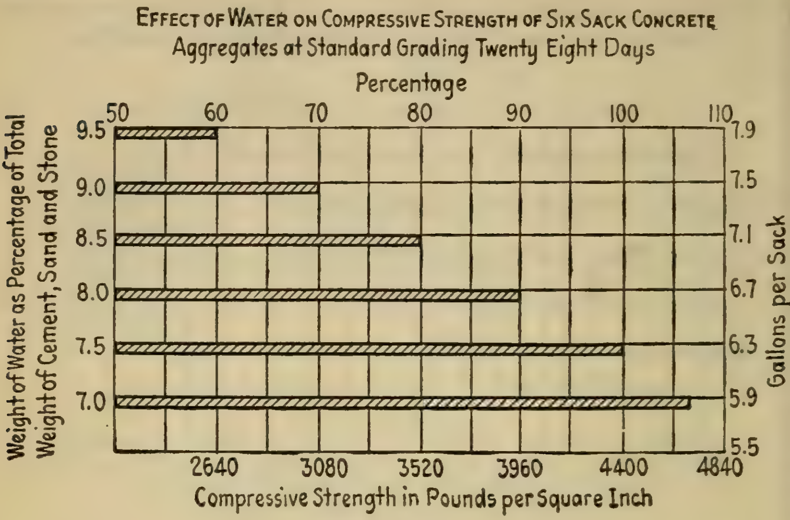


CHART *D*.

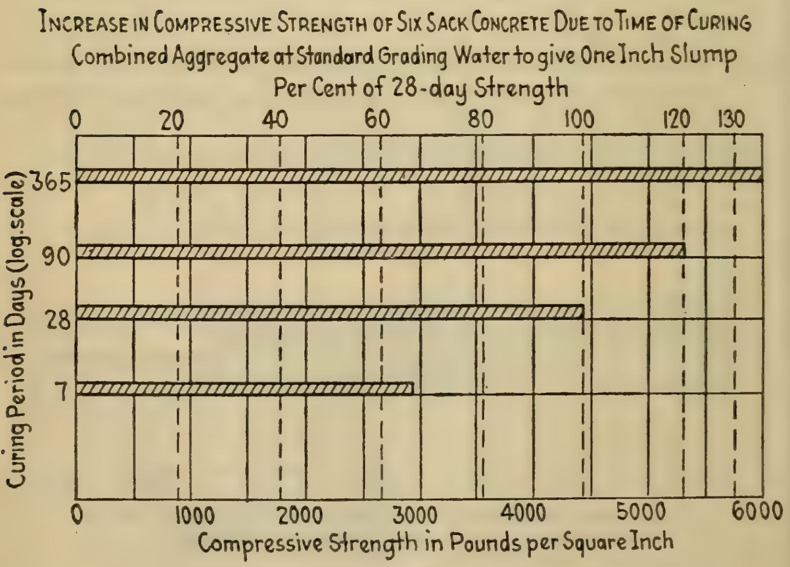


CHART *E*.

Chart D.—This table shows effect of water on compressive strength and is founded on tests in our own laboratory, on tests in Bulletin No. 58 of the Bureau of Standards, and on tests by Professor Abrams.

Chart E.—This chart shows increase in compressive strength with increased time of curing. The values shown will vary more with conditions than those given in other tables. In this instance the values are based on mean temperatures of 70 deg. or higher. Lower temperatures will retard curing time.

Bituminous-concrete Pavements

General Discussion.—Ordinary asphalt surfaces are probably familiar to most readers. An asphaltic-concrete surface is merely a well-graded mineral aggregate mixed and cemented with bitumen. This general type includes sheet asphalt, Topeka Mix, Warren Bros. Bitulithic, Amiesite, Bito slag, and various other trade-name products. These surfaces are laid on either macadam or cement-concrete bases. Specifications (p. 1459) describe construction operations in detail.

Asphaltic-concrete surfaces are satisfactory and economical for the heavier-traffic Class I rural roads having a traffic volume of over 3000 vehicles daily (10-hr. count) and for resurfacing of any road carrying over 1500 to 2000 vehicles daily. The essential advantage of this type lies in its pleasing appearance, ease of construction and repair, and resilient quality, which makes it particularly resistant to traffic damage of a large volume of mixed traffic.

The high cost of this surface eliminates its use on unimportant roads.

It has been extensively used for resident city streets and a considerable mileage has been constructed on primary state-system rural highways. In damp weather, it is often quite slippery for high-speed rural traffic—a drawback—but it is at present (1926) the most available type for resurfacing worn-out rigid pavements and for capping old solid macadam bases on roads of Class I and II*A*, and it is certain that a considerable yardage of this type will be constructed on rural highways, particularly under reconstruction programs. Scientific grading of aggregates and care in construction do much to reduce the faults of waving and extreme slipperiness, although these fundamental faults are difficult to prevent entirely.

Asphaltic-concrete pavements, including concrete or macadam bases, cost for initial construction from $3 to $4 per square yard; the yearly maintenance has a wide range, but probably falls between 0.4 to 3.5 cts. per square yard for narrowrural high ways. The cost of surface renewal distributed over the life of the surface probably is about 8 to 15 cts. per square yard per year on narrow rural highway pavements (1926 cost conditions where the traffic volume is more than 3000 daily).[1]

The proper grading of aggregate is a complicated study and the reader is referred to books by Richardson, Hubbard, etc. for complete data. Specifications (p. 1459), show usual practice for rura

[1] Renewal costs based on maximum allowable Vialog coefficient of 250 without excessive maintenance (see p. 551).

highway pavements. The present tendency lies towards the use of increasing percentage of larger stone fragments under moderate-traffic volume to reduce slipperiness and the formation of waves. Under extremely heavy traffic, a fine aggregate is desirable to prevent pitting of the surface. A conservative estimate of surface life for this type on heavy-traffic rural roads is about 10 to 15 years, although there are many cases which do not fall within these limits (see Chap. VII).

Recommended Designs.—The recommended designs represent conservative practice. It is undesirable to reduce the thickness of base below the depths shown, as this type of pavement cannot be easily strengthened by future resurfacings. These designs are based on maximum gross vehicle load of 28,000 lb.

Suitability of Materials. *Macadam Bases.*—See Water-bound and Bituminous Macadam Pavements (pp. 429 to 449).

Concrete Bases. Cement.—Same as for concrete pavements (p. 456).

Coarse Aggregate. (Paving Base).—Any clean, hard, well-graded size of crushed stone, gravel, or 1800 lb. per cubic yard

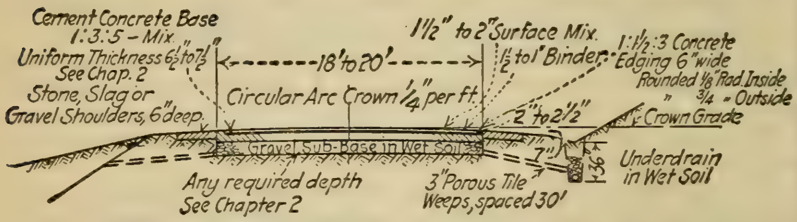


FIG. 165.—Recommended design Class I traffic.

crushed slag. Pit-run gravel or crusher-run stone should not be used; the sizing for coarse aggregate is generally specified as between ¾ to 3½", with not over 15% of material passing the 1¼" screen The high standards set for concrete pavement need not be attained, as the base is not subjected to traffic pounding. It must produce a strong concrete; it is desirable to use the best available source without raising the cost needlessly; in the main, a local supply should be preferred even if the coefficient of hardness drops as low as 5 for stone or this equivalent for gravel. Shale gravel shall not be used but a small percentage of shale up to 10% is allowable. The coarse aggregate must, however, be free from organic impurities and from a coating of clay or loam.

Sand (Paving Base).—Same general requirements as for concrete pavements except that an 8% maximum loam content can be used with safety (see Specifications, p. 1386).

Binder and Surface Mix—The following material from the "Asphalt Association Handbook" is as authoritative as any available data.

COARSE AGGREGATE—BROKEN-STONE SPECIFICATIONS

For Asphaltic Concrete, Coarse-graded Aggregate Type

Size	Per cent passing screen			
	1¼″	¾″	½″	¼″
Coarse aggregate........	95–100	25–75	......	0
Cover for seal coat......	......	.....	95–100	0–15

Per cent of wear, 5.

For Asphaltic Concrete, Fine-graded Aggregate Type

Coarse aggregate	Per cent passing screen		
	¾″	½″	¼″
Alternates			
I..........................	...	95–100	0–75
II..........................	100	......	0–75

For Binder Course

	Per Cent
Passing 1¼″ screen......................	95–100
Passing ¾″ screen......................	25– 75
Passing ¼″ screen......................	0– 10
Per cent of wear......................	6

For Two-course Asphalt-macadam Base

	Per cent passing screen				
	3½″	2½″	1¼″	1″	¾″
No. 1 coarse...........	95–100	0–15			
No. 2 coarse...........	......	95–100	0–15		
Intermediate...........	......	......	95–100	25–75	0–15

Per cent of wear, 8.

For Asphaltic-concrete Base

Coarse aggregate, inches	Per cent passing screen				
	2½″	1½″	1¼″	¾″	¼″
Alternates:					
I....................	95–100	......	25–75	.....	0
II....................	......	95–100	.....	25–75	0

Per cent of wear, 5.

Broken-slag[1] *Specifications.*—Broken slag may be used in place of broken stone for the various types of asphalt pavements and bases, the requirements for size being the same as those given under Broken-stone Specifications. In addition, the following requirements are commonly made:

Per cent of wear.................... 10 per cent —.
Weight per cubic foot for each size specified.......................... 70 lb. +

Gravel[1] *Specifications.*—Gravel may be used in place of broken stone for coarse-graded-aggregate asphaltic concrete, binder coarse and asphaltic-concrete base with the same requirements for size as those given under Broken-stone Specifications. The gravel should be composed of sound, hard, durable pebbles free from clay or coatings of any character.

SAND OR FINE-AGGREGATE SPECIFICATIONS

Coarse-graded Aggregate Asphaltic-concrete and Asphaltic-concrete Base

Passing	Retained on	Per cent
¼″ screen..........................	....	100
¼″ screen..........................	10-mesh sieve	0–20
10-mesh sieve......................	40-mesh sieve	15–20
40-mesh sieve......................	80-mesh sieve	25–60
80-mesh sieve......................	200-mesh sieve	7–40
200-mesh sieve.....................	....	0– 6

Fine-graded Aggregate Asphaltic Concrete and Sheet Asphalt

Passing	Retained on	Per cent	
10-mesh sieve................	....	98–100	
10-mesh sieve................	20-mesh sieve	3– 15	14–50
20-mesh sieve................	30-mesh sieve	4– 15	
30-mesh sieve................	40-mesh sieve	5– 25	
40-mesh sieve................	50-mesh sieve	5– 30	30–60
50-mesh sieve................	80-mesh sieve	5– 40	
80-mesh sieve................	100-mesh sieve	10– 20	16–40
100-mesh sieve...............	200-mesh sieve	6– 20	
200-mesh sieve...............	....	0– 5	

The sand shall consist of clean, hard, durable grains free from clay, loam, and other foreign matter.[2]

Mineral-filler Specifications.—Limestone dust, slate dust, or Portland cement.

	Per Cent or More
Passing 30-mesh sieve......................	100
Passing 200-mesh sieve.....................	60

[1] Gravel or slag is not advised where a good grade of stone is available.
[2] Heat from drying drum generally eliminates all organic impurities except free matter like sticks or leaves.

Bitumen.—Detail specifications for suitable asphalt and tar binders are given on page 1399.

A considerable range in the value of penetration, depending on climatic and traffic conditions, is the only point necessary to indicate at this part of the discussion. The values recommended for asphalt are as follows:

Table 94.—Penetration Values for Asphaltic Concrete

Traffic	Temperature		
	Low	Moderate	High
Light	60–70	60–70	50–60
Moderate	60–70	60–70	50–60
Heavy	50–60	50–60	50–60

Table 95.—Penetration Values for Sheet Asphalt

Traffic	Temperature		
Light	50–60	50–60	40–50
Moderate	50–60	50–60	40–50
Heavy	40–50	40–50	30–40

If a tar binder is used the usual grade corresponds to Tarvia X (Barrett Company Specifications).

Amounts of Material. *Macadam Bases.*—See Water-bound and Bituminous-macadam Pavements (pp. 441 to 449).

Cement-concrete Bases per Cubic Yard

Mix	Coarse aggregate, cubic yards	Sand, cubic yards	Cement, barrels
1:3 :6	0.95	0.47	1.0
1:2½:5	0.92	0.46	1.2
1:2 :4	0.90	0.45	1.5
1:1½:3	0.84	0.42	1.9

Asphaltic Mixes.—The following data are taken from the "Asphalt Association Handbook" and applied to unpatented mixtures:

Coarse-graded Aggregate Asphaltic Concrete
(2″ thick, excluding seal coat)

Materials	Pounds per square yard	Tons per mile, 1′ wide
Coarse stone	147	43.1
Sand	58	17.0
Mineral filler	9	2.6
Seal-coat stone	25	7.3
Asphalt	18	5.3

Fine-graded Aggregate Asphaltic Concrete (Modified Topeka)
(2″ thick)

Materials	Pounds per square yard	Tons per mile 1′ wide
Stone chips	53	15.5
Sand	123	36.1
Mineral filler	18	5.3
Asphalt	18	5.3

Asphaltic-concrete Base
(3″ thick)

Materials	Pounds per square yard	Tons per mile 1′ wide
Coarse stone	216	63.4
Sand	100	29.3
Asphalt	18	5.3

"On western New York State Highways black base using a limestone aggregate and sand proportion approximately 75% stone and 25% sand, the weight per cubic yd. of consolidated material has ranged between 3500 and 3700 lb. exclusive of bitumen."

Amiesite.—This is a patented pavement made of crushed stone coated with asphaltic cement. It has been used on many miles of road with good results. It is shipped cold in a friable and granulated state, spread on either macadam or concrete base, and well rolled. Amiesite screenings are then spread and rolled, forming the surface. This construction costs about the same as asphaltic concrete per square yard. It resembles asphalt in appearance and has the advantages and disadvantages of all roads of this class. It is particularly adapted for small jobs where it would not pay to set up an asphalt plant or where suitable asphalt materials are not locally available.

TABLE 96.—DEPTHS AND WEIGHTS OF AMIESITE

(Weights are given per square yard)

	Amiesite loose, inches	Weight, pounds	Amiesite, square yards per ton	Filler loose, inches	Weight, pounds	Filler, square yards per ton	Total depth loose, inches	Total weight, pounds	Ultimate, compression, inches	Square yards per ton
Sandstone	2¼	153	13.0	1	67¾	29.5	3¼	220¾	2	9.06
	2⅝	178½	11.3	1	67¾	29.5	3⅝	246¼	2¼	8.12
	3	204	9.8	1	67¾	29.5	4	271¾	2½	7.36
	3⅜	229½	8.7	1	67¾	29.5	4⅜	297¼	2¾	6.73
	3¾	255	7.8	1	67¾	29.5	4¾	322¾	3	6.20
Trap rock	2¼	168¾	11.8	1	75	26.6	3¼	243¾	2	8.20
	2⅝	196⅞	10.2	1	75	26.6	3⅝	271⅞	2¼	7.36
	3	225	8.9	1	75	26.6	4	300	2½	6.66
	3⅜	253⅛	7.9	1	75	26.6	4⅜	328⅛	2¾	6.10
	3¾	281¼	7.1	1	75	26.6	4¾	356¼	3	5.60
Limestone	2¼	164¼	12.2	1	73	27.4	3¼	237¼	2	8.43
	2⅝	191⅝	10.4	1	73	27.4	3⅝	264⅝	2¼	7.56
	3	219	9.1	1	73	27.4	4	292	2½	6.85
	3⅜	246⅜	8.1	1	73	27.4	4⅜	319⅜	2¾	6.26
	3¾	273¾	7.3	1	73	27.4	4¾	346¾	3	5.77

NOTES.—To find the amount of loose Amiesite necessary for any compressed thickness, subtract ½″ from compressed thickness, multiply by 1½, which equals loose thickness, to which add 1″ for filler.

To find what compressed thickness any given amount of loose Amiesite will give, subtract 1″ from loose thickness, multiply by ⅔, and add ½″ for filler.

Design.—Design includes decisions in regard to the selection of either macadam or cement concrete as the base, the depths of base required for the soil and traffic conditions prevailing, the width and crown of the pavement, and the mix and depth of the bituminous concrete surface.

Type of Base.—Macadam base is an economical design for moderate traffic where the macadam is constructed at least a year ahead of the asphalt surface. Macadam bases are rarely desirable where the asphaltic surface is laid on newly constructed macadam, as traffic pounding is necessary in order to compact macadam construction properly.

Cement-concrete base is the most feasible type for heavy traffic where it is desirable to get quick results on new grading, but should be used with caution on new fills of depths of over 2 to 3′ unless special care is taken in grading operations. Despite all care, it is not advisable to use concrete base on fills over 5′ deep or on side-hill sections part in cut and part in fill unless the grading is at least 1 year and preferably 2 years old.

Depth of Base.—If the macadam type of base is selected, it is merely a matter of macadam design. The required depths and the most economical use of local materials were discussed under

Macadam Design and the reader is referred to (pp. 366 to 392) and Macadam Pavements (pp. 429 to 449).

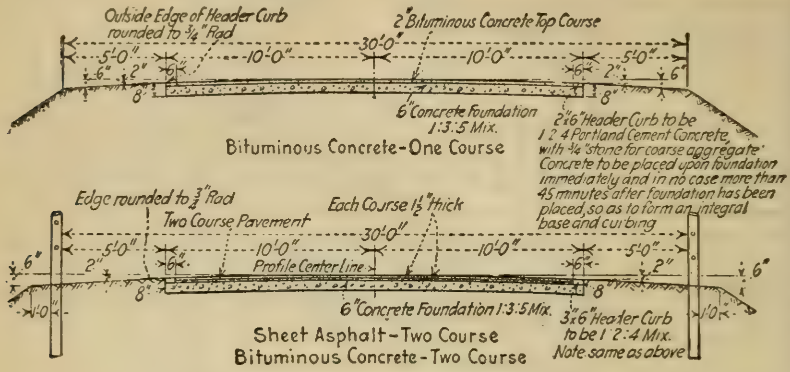


FIG. 166.—State of New Jersey (1922).

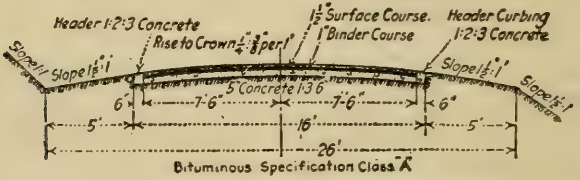


FIG. 166.—State of Pennsylvania (1922).

CONTRACTION AND EXPANSION OF MORTAR AND CONCRETE

Mortars		Concretes	
Mixture	Coefficient of expansion per degree Fahrenheit	Mixture	Coefficient of expansion per degree Fahrenheit
Neat	0.000,007,83	1:1½:3	0.000,006,77
1:1	0.000,007,43	1:2 :4	0.000,006,60
1:2	0.000,006,00	1:2½:5	0.000,005,58
1:3	0.000,006,05	1:3 :6	0.000,005,37
1:4	0.000,005,94		
1:5	0.000,005,77		

Coefficient of expansion. Steel reinforcement 0.000,006,5.

If the concrete type of base is selected, it is necessary to decide on the richness of the mix and the depth of base. Engineers differ as to the desirability of the different mixes, which range in common practice from 1:3:6 to 1:2:4. For the same strength, the leaner mixes require greater depth, and they are also a little more likely to be porous and to break down over trenches, but transverse contraction cracks seem less noticeable with the leaner mixtures, probably on account of lower coefficient of expansion and contraction. The tendency is towards the use of 1:2½:5 or 1:3:5 as a good practical mix. The depths of base recommended for dif-

ferent mixes under different traffic loading is given in Table 86 (p. 426) and ranges from 6 to 8″.

Surface Mix.—The surface mix is generally in two layers, binder and finer-aggregate mix. The depths range from 2″ where binder is not used to 3″ for the heavier-traffic streets (1 to 1½″ binder and 1½ to 2″ fine-aggregate top).

Figures 165 and 166 show the depths of binder and fine mix in common use (1926) on rural highways. Personally, the author prefers 1″ closed binder and 1½″ Modified Topeka Surface Mix for ordinary highway work. On extremely heavy-traffic road, a 1½″ binder with 1½″ of fine-graded mix is probably better for such conditions. There is an infinite variety of mixes, depending on materials available and local climatic and traffic conditions, and the best mix to adopt is largely a local problem which can be best solved by an expert asphalt man and gradually modified by observed action for any locality. Practically all authorities are agreed that the most common serious fault of surface mixes lies in insufficient fine sand passing 80 and being retained on 200 sieve, insufficient or poor-grade filler passing 200, and a poor relation between the proportions of fine sand, 80 to 200, to the amount of filler and bitumen. *The lack of durability of many pavements is directly chargeable to carelessness in grading.* The following typical mixes are recommended by the Asphalt Association and should serve satisfactorily in case local practice has not crystallized on a somewhat different mix. The reader is referred to books by Clifford Richardson, Provost Hubbard, Besson etc., for detail data on asphalt mixtures.[1]

TYPICAL MIXES RECOMMENDED BY ASPHALT ASSOCIATION

Asphaltic-concrete Surface Course

(Fine-grade aggregate type)

Thickness, 2″.
Crown, ¼″ to ⅜″ to the foot recommended.
Materials (see preceding discussion).
Mixture:

	Per Cent
Passing ½″, retained on 10-mesh screen	20.0–35.0
Passing 10-mesh, retained on 40-mesh sieve	7.0–25.0
Passing 40-mesh, retained on 80-mesh sieve	11.0–36.0
Passing 80-mesh, retained on 200-mesh sieve	10.0–25.0
Passing 200-mesh sieve	7.0–11.0
Bitumen (asphalt cement soluble in carbon disulphide)	7.5– 9.5

Sheet-asphalt Binder and Surface Courses

Thickness:

Binder course	1½″ recommended
Wearing course	1½″ recommended
Total	3″

Crown, ¼″ to the foot recommended.
Materials (see preceding discussion).
Mixtures:

[1] See Richardson, "Asphalt Construction," McGraw-Hill Book Co., Inc., p. 70. See Besson City Pavements McGraw Hill Book Co. Inc.

	Per Cent
Binder course:	
Coarse aggregate retained on 10-mesh sieve	60.0–80.0
Sand and material passing 10-mesh sieve	15.0–35.0
Bitumen (asphalt cement soluble in carbon disulphide)	4.0– 6.0
Surface course:	
Passing 10-mesh, retained on 40-mesh sieve	10.0–40.0
Passing 40-mesh, retained on 80-mesh sieve	22.0–45.0
Passing 80-mesh, retained on 200-mesh sieve	12.0–30.0
Passing 200-mesh sieve	10.0–20.0
Bitumen (asphalt cement soluble in carbon disulphide)	9.5–12.0

Probably the simplest way for the student to consider an asphalt mixture is in two steps: first, the asphaltic mortar composed of bitumen and all the mineral aggregate passing a No. 10 sieve, and, second, the coarse mineral aggregate retained on the No. 10 sieve. The mortar must conform to the requirements of a good sheet asphalt, all ingredients of which pass a No. 10 sieve, and the amount of coarse aggregate added to the mortar has no effect on proportioning the mineral aggregate of the mortar, although it does have some effect on the total bitumen in the final mix.

Good representative ideal mortar mixes used in northern states for different volumes of traffic are shown in the table on page 501.

It is important to have from 10 to 12% of bitumen to insure good life, waterproofing, etc., but in order to carry the proper amount of bitumen and still have a good workable and stable mix the proportion of bitumen, 200 and 80 factors, must be about as shown. A good grade of filler (200 sieve) is important. Limestone dust or Portland cement make the best and most dense product, but it is rarely advisable to eliminate the 200-mesh sand content entirely although it is probably justifiable to restrict the 200-mesh sand to a maximum of 5% of mortar mix and make up the balance with the cement or stone-dust filler.

The second factor (coarse-stone aggregate $\frac{1}{10}$ to $\frac{1}{2}''$ in size) is added to increase stability of mix under traffic, to decrease slipperiness of the pavement, and to reduce the cost of the mix. For the ordinary so-called modified Topeka, which is a popular type, the amount of coarse stone ranges from 15 to 30 lb. per 100 lb. of total surface mixture. This coarse aggregate consists of the stone coated with bitumen. The amount of bitumen necessary to coat the stone of the size usually used is about 2% of the weight of the stone.

The final proportions of a mix consisting of both mortar and coarse aggregate can now be very easily computed. Suppose it is proposed to figure an ideal mix using 20 lb. of coarse aggregate and 80 lb. of mortar, making 100 lb. of completed surface mix. The amount of each factor in the mortar content of the final mix is obtained by multiplying the percentages given in the preceding table by 80 lb. The amount of bitumen figured for the mortar is then increased by 2% of the weight of the coarse aggregate (20 lb. $\times$ 0.02 = 0.4 lb.) and the net weight of coarse aggregate is added as a new factor. The table on page 501 of ideal mix for Topeka construction is computed in this manner:

ASPHALTIC-MORTAR MIX (PERCENTAGES BY WEIGHT)

Class of traffic	Bitumen, per cent	Mineral aggregate				Total all factors, per cent
		200 sieve	80	40	10	
Light......	10.0	10.0	15	30	35	100
Medium....	10.5	12.5	18	34	25	100
Heavy.....	11.0	15	21	34	19	100
Allowable variation (per cent each size or factor)..	9.5–12	10–20	12–30	22–45	10–40	
	The relation of these columns must remain about constant, that is, they must all rise or fall together.			This column should not be much over twice the 80 column.	This column not so important.	

TABLE OF IDEAL PROPORTIONS, MODIFIED TOPEKA MIX
(Surface mix—percentages of complete mix by weight)

Class of traffic	Bitumen	Mineral aggregate						Total all factors
		200 sieve	80	40	10	¼″	½″	
Light.........	8.2	7.0	12	22	26	17	8	100
Medium......	8.8	9.2	14	25	21	15	7	100
Heavy........	9.5	11.5	17	28	16	13	5	100
Allowable variation (per cent for each size factor)..	8–10	7–12	10–25	11–36	7–25	10–20	Less than 10	

Binder.—The binder course may be of either the so-called "open" or "closed" types. Open binder is merely asphalt- or tar-coated stone ranging in size from ⅝ to 1¼″. This type of binder requires from 3.5 to 4.5% of bitumen. The closed binder is more nearly a true asphaltic concrete and requires careful grading of aggregate. By courtesy of Clifford Richardson the following is quoted from his book "Asphalt Construction."[1]

"**Open Binder.**—Open binder consists of stones largely of one size, the fragments being from ¾ to 1″ in their largest diameter, although at times run of crusher has been used. Broken stone of the latter description requires a larger amount of bituminous cementing material, and in consequence the binder is more cohesive. The following data will show the average composition of open binders which have been used at different times in the construction of sheet-asphalt pavements.

"It appears from these figures that the percentage of bitumen which a binder requires depends largely upon the amount of fine material which it contains. The first mentioned in the table contains 26.8 % of fine material

[1] "Asphalt Construction," McGraw-Hill Book Company, Inc.

AVERAGE PERCENTAGE COMPOSITION OF OPEN BINDERS USED IN SHEET-ASPHALT PAVEMENT

	Test No.				
	69978	70804	70854	71102	74893
Bitumen	5.4	4.4	3.8	3.6	3.5
Filler	5.8	4.1	2.2	2.4	1.5
Sand	21.0	12.5	7.5	3.0	3.0
	26.8	16.6	9.7	5.4	4.5
Stone:					
Passing 1/4" sieve	5.8	8.7	18.0	13.5	49.5
Passing 1/2" sieve	13.6	46.8	52.0	51.5	10.0
Passing 1" sieve	41.4	23.5	16.5	26.0	32.5
Retained 1" sieve	7.0	0.0	0.0	0.0	0.0
	67.8	79.0	86.5	91.0	92.0
	100.0	100.0	100.0	100.0	100.0

and requires 5.4 % of bitumen while those made from cleaner stone where the finer particles do not exceed 5%, contain less than 4% of bitumen. In preparing sending to the street, and placing a course of open binder, care i demanded in certain directions The stone should be hard, suffi ciently so as not to crush under th roller. It should be free from cla and dirt, although, as has bee said, fine particles of the ston itself are an advantage rathe than otherwise. In heating th stone and mixing it with th asphalt cement, great care shoul be used so that it is not overheated since if this is the case a prope coating of the bonding materia will not adhere to the stone, owin to the excessive heat, or much c it may run off and be lost durin the haul to the street. On th other hand, the binder should b hot enough to permit of properl coating it and its ready compres sion on the foundation. An ope binder should be bright and gloss and not dead in appearance, as is dumped from the truck. I should be hot enough to sprea readily and uniformly. It shoul contain no excess of bitumen a any one spot, and, should this b the case, such spots should b removed and replaced. Binde after it has been placed on th street or road, should be covere within the shortest space of tim possible, with the surface, as whe it has been wet, tracked with dir or become covered with horse drop pings or dead leaves, the adhesio of the surface mixture to it wi not be complete.

"In actual practice a 9-cu. f box of broken stone for binder wi weigh about 900 lb., will requi about 40 lb. of Trinidad and abou 36 lb. of Bermudez asphalt cemen but the cement must be regulate by observing the appearance of th material in the truck and on th street.

"In preparing a binder at th plant the mixer in use should hav teeth with a sufficient clearanc between them and the lining of th mixer so that the largest particle of stone cannot become wedge between them, and thus rapidl wear out the lining of the mixe It is not good practice to attemp to mix binder in the same mixe that is employed for preparing th surface mixture. A separate on should be employed, although i

some of the smaller plants of a portable description it is not always possible to do so, in which case provision must be made for making a change of teeth from the longer to a shorter form, in changing from surface to binder mixing."

Close Binder.[1]—Close binder is, or should be, a true asphaltic concrete. It consists of the same broken stone of which the open binder is made, but the voids in it are filled with smaller stone and with an asphaltic mortar corresponding to the ordinary asphalt surface mixture. For the construction of a close binder or asphaltic concrete of the highest type, the grading of the mineral aggregate should be carefully regulated. This can be done by determining the voids in the coarser stone, calculating the amount of fine stone necessary to fill these, and again the amount of sand to fill those in the mixture of coarse and fine stone. This can be readily done by constructing a box of sheet iron or wood of exactly 1-cu. ft. capacity. It is filled with the hot, coarse stone, which is compacted by shaking. The surface is then struck off and the box weighed. Allowing for tare, the weight of 1 cu. ft. of the coarse stone is obtained. Knowing the density of this stone, 2.65 for limestone and 2.9 to 3.0 for trap rock, the weight of a solid cubic foot of the stone can be calculated. By dividing the weight of a cubic foot of the broken stone by the weight of a solid cubic foot of the material, the voids can be determined. In the same way the weight of a cubic foot of the finer stone and of sand can be arrived at. The amount of each which it is necessary to use to fill the voids in the coarse stone, and again in the mixture of the coarse and fine stone, can be readily calculated. The proportions for actual use can be readily determined and the amount of bitumen required from the percentages of broken stone and sand that are present.

As an example of the proportions of coarse stone, fine stone, sand, and asphalt cement in actual use in preparing a close binder, the following figures will serve:

	New York		Boston
	Plant 1	Plant 2	
Coarse stone	480 lb. = 54.6%	480 lb. = 53.3%	885 lb. = 73.4%
Fine stone	200 lb. = 22.7%	202 lb. = 22.4%	
Sand	150 lb. = 17.0%	150 lb. = 16.7%	250 lb. = 20.8%
Trinidad asphalt cement	....	68 lb. = 7.6%	70 lb. = 5.8%
Bermudez asphalt cement	50 lb. = 5.7%		
	880 lb. = 100.0%	900 lb. = 100.0%	1205 lb. = 100.0%

ANALYSES, PER CENT

Bitumen soluble in CS_2	5.6	....	5.2	....	4.8	
Passing 200-mesh screen	4.4	....	6.4	....	4.2	
Passing 10-mesh screen	29.2	33.6	29.0	35.4	26.4	30.6
Passing 8-mesh screen	1.8	....	2.0	....	0.8	
Passing ¼" screen	10.0	....	7.0	....	4.4	
Passing ½" screen	23.2	....	25.8	....	24.4	
Passing ¾" screen	13.6	....	17.8	....	32.2	
Passing 1" screen	7.4	....	6.8	....	2.8	
Retained 1" screen	4.8	....	0.0	....	0.0	
	100.0	....	100.0	....	100.0	

"At some plants it is impossible to separate the stone into coarse and fine particles, in which case the heated stone of both sizes is collected in one bin, but segregation generally occurs under such circumstances. In arranging the grading of the mineral aggregate, care should be taken to see that the

[1] Quoted from RICHARDSON, CLIFFORD, "Asphalt Construction," McGraw-Hill Book Company, Inc.

amount of fine material, while sufficient to fill the voids in the stone, is not present in excess, since in this case the surface of the binder when compacted on the street will be too smooth to bond properly with the wearing surface, and resulting displacement under travel will be possible. An excess of bitumen must also be avoided for the same reason, and if spots in the binder as laid show anything of this description, the material should be removed.

"An entirely satisfactory close binder can be constructed for all but the most trying conditions by the use of selected old surface material, which has been disintegrated and softened by steam, for filling the voids in the ordinary open binder. It is, of course, a matter of great economy to turn out a close binder in this manner. The old surface material, having been crushed and softened by dry steam, is added in the mixer to the hot binder stone and, in this manner, further disintegrated and distributed among the stone. The proper amount of additional asphalt cement is added to coat the stone and enrich the old surface mixture. It does not possess the complete stability of an asphaltic concrete, but it is infinitely superior to the ordinary open binder for the construction of an intermediate course.

"The asphalt cement in use in binder may well be considerably softer, 10 to 15 points, when it is possible to make it so, than that in use in the sheet-asphalt surface.

"In the construction of asphalt pavements with an asphaltic concrete binder course, the surface should be applied to it before it has become entirely cold. It is well to run out binder to the street for not more than half of a working day and to cover it with surface during the same day. This is much more important with a close than with an open binder. It is not possible to do satisfactory work where a large area of close binder is laid on one day and covered with surface on the next."

FIG. 167A.—City street pavement crowns, Rochester, N. Y

Width and Crown.—Normal widths for heavy-traffic roads on which asphaltic concretes can be economically used range from 18 to 20′ on straight alignment. On sharp curves these widths are increased (see Tables 36 and 37, p. 132).

Either the parabolic or circular-arc crown is suitable; as discussed under Concrete Pavements, the circular arc is to be pre-

ferred. A crown slope of ¼ to ⅜″ per foot is usual practice. For rural highways, ¼″ is probably the better rate. For village streets of considerable width, Fig. 167 page 505 shows current practice for different types of pavement. As the grade increases the crown is reduced. On sharp curves, a one-way banked crown is used (see p. 127 for ordinary practice).

Steep Grades.—See pages 425 and 101 for limitations of use imposed by steep grades.

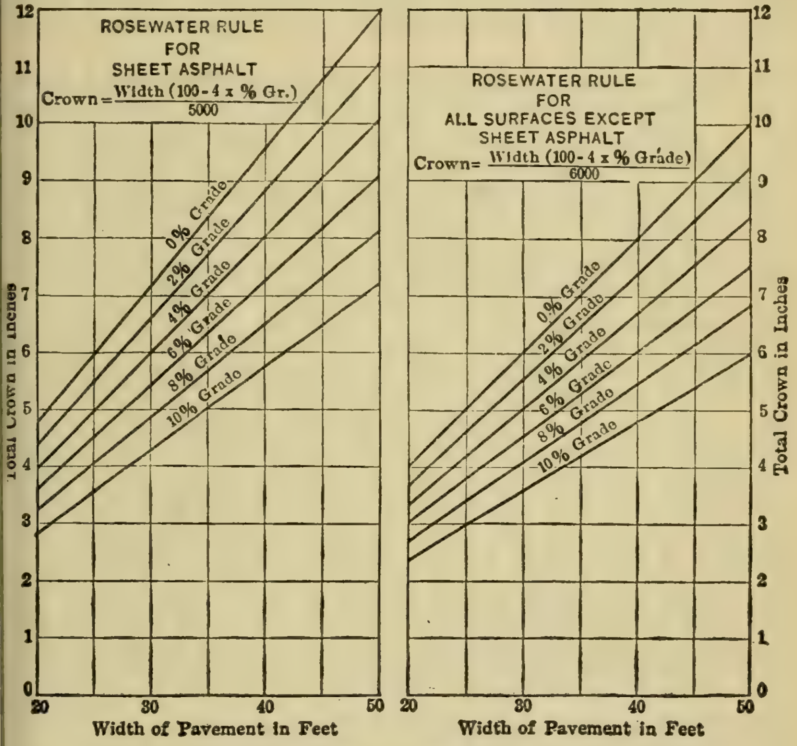


FIG. 167*B*.—City street crowns, "Rosewater Rule."

Specifications.—See Part III (pp. 1459 to 1470).

Construction Equipment.—See Chap. XV (pp. 1264 to 1265).

Inspection Details.—See Chap. XVI (pp. 1313 to 1330).

General Maintenance Methods.—Usual methods of shoulder, ditch, and guard-rail work prevail. The pavement is repaired by cutting out the depressions or waves which develop and replacing the surface mix; this can be easily and quickly done with very little inconvenience to traffic (see Chap. VII for costs, etc.). Temperature cracks are sealed with liquid bitumen.

Brick Pavements

General Discussion.—All readers are familiar in a general way with the character of brick pavements. They are merely specially hard, well-manufactured brick set on either a cement-sand, bituminous-sand, or sand cushion and the joints between the brick filled with cement grout, bituminous filler, or, in unusual conditions, plain sand. The foundation for the brick surfaces is generally cement concrete ranging in depth from 5 to 8″. In some cases firm macadam foundations can be utilized to advantage in place of the cement-concrete base. Specifications (p. 1476) describe construction operation in detail.

Brick pavements are satisfactory for the heavier Class I traffic roads. They have been used extensively for city pavements and for a considerable mileage of primary state highways. The economy of their use depends largely on the location of the road in relation to the brick-manufacturing plant, as the item of freight has of late years been the cause of a serious curtailment of the use of this type of road. There have been cases where brick roads close to brick plants cost about as much as at greater distances but this is an artificial condition due to lack of competition and tc the manipulation of sale price, situations which are likely tc develop with any material. Well-manufactured paving brick is an excellent surfacing material, as the pavement is pleasing in appearance, having a warm, neutral tone; it is a safe surface fo high-speed travel; it absorbs very little moisture and has n tendency to push into humps or waves. For rural highwa conditions, however, the initial cost is usually so much highe than other acceptable types that it is rarely selected on the score o economy under moderate traffic, and where it is used (largely fo portions of rural roads passing through village business streets the selection is based on the factors of extremely heavy traffic appearance, and local preference for the type. It seems a pit that such an excellent material has been so badly handicapped b freights and by an adherence to a form of brick which may perhap be modified to advantage for rural highway conditions. The siz of the proposed highway program demands the use of all availabl materials, and clay products are so widely distributed that it seem ridiculous not to make more use of this excellent material. Som attempts have been made to modify brick-pavement practice t make it more applicable for the ordinary rural road. Thes attempts have not been entirely successful but show sufficien promise to warrant more serious consideration of modifications i practice. The cube method is described on page 516. Reductio in thickness of paving brick is receiving attention and there is con siderable evidence of successful progress along this line of modifyin old style practice particularly for moderate traffic conditions.

Standard 4″ brick pavements, including base, cost, for initial con struction, from $3.50 to $5.00 per square yard, 1926 cost conditions the yearly maintenance has a wide range due to all sorts of condi tions, but probably falls between 0.3 to 4 cts. (1.5 average) pe square yard. The cost of surface renewal distributed over the lif

of the pavement is probably about 10 to 16 cts. per square yard per year for rural highway conditions on primary roads carrying over 4000 vehicles daily.[1] A reasonable surface life for heavy-traffic roads constructed of this type is probably about 12 to 18 years, although there are many cases which do not fall within these limits (see Chap. VII).

There are three general types of brick pavement:

1. Monolithic base and top with cement-grout joint filler.
2. Semimonolithic type with cement-concrete base, cement-sand, or bituminous-sand cushion and either cement-grout or bituminous joint filler.
3. "Rolled base" with some type of macadam or gravel base surfaced with brick having either bituminous or cement-grout joint filler.

The monolithic type is constructed by laying the brick on the green concrete base having a skim coat of cement sand before the base has set; in this way a fairly good bond between base and top course of brick is obtained. The purpose of this construction was to produce a monolithic slab, and by this means reduce the necessary depth of concrete base. It has not proved as effective as its originators hoped. The semimonolithic is the best-known construction; it depends largely for its strength on the concrete base, which is constructed and allowed to set before the surface is constructed. On this base an evener cushion of sand or a mixture of sand and cement or bitumen and sand is spread, and the brick surface laid and filled with either cement grout or bitumen. The "rolled-base" type is essentially the same as the semimonolithic, except that macadam or gravel is substituted for the cement-concrete base.

The monolithic type should be used with caution, in northern climates at least, as it does not seem to meet conditions as well as the second class. The rolled-base type should be used with caution under extremely heavy traffic, and even under moderate traffic it has some disadvantages, due largely to the shape of the standard block. The best type of brick pavement appears to be the second class noted above.

If the second class (semimonolithic) is used, there is considerable disagreement between engineers in regard to the use of cement-sand cushion as against bituminous-sand cushion and in regard to the use of cement-grout filler as against bituminous-mastic filler. Assuming that the base is strong enough to prevent failure due to weakness of the pavement and that the brick are uniformly well manufactured and stand the traffic pounding, the surface defects which develop are due either to temperature cracking or blow-ups or spalling at joints. Cracking and blow-ups are reduced by the use of bituminous filler in place of grout filler; joint spalling is reduced by the use of cement-grout filler. Excellent pavements can be constructed by either method. In villages where appearance is a large factor, and where it may be necessary to take up areas of pavement, the author personally favors the cement-sand cushion with bituminous joint filler. On

[1] These renewal costs are based on a maximum permissible Vialog rating of 250″ per mile without excessive ordinary maintenance charges.

rural highways outside of villages where appearance is not such a large factor, the author prefers the cement-sand cushion with cement-grout filler, as, while a small percentage of cracks will occur, the pavement is not seriously damaged its riding quality for high-speed traffic is bettered and joint wear reduced. Recent tests on the Bates Road (1922) seem favorable to the bituminous sand cushion. Recent tests (1926) U. S. Office of Public Roads are summarized as follows.

Conclusions Indicated by the Investigation.—The several parts of the investigation have now been completed and the analysis of the data obtained seem to warrant certain conclusions, among which the more important are:

1. That 2½-in. brick of the quality used in the Arlington traffic tests, when properly supported, will prove satisfactory for pavements carrying the heavier types of traffic.
2. That brick of 2-in. thickness, when properly supported, and of the quality used in the tests, will be adequate for pavements on streets carrying the lighter types of traffic.
3. That a bedding course of plain sand is more effective in reducing breakage of brick than a cement-sand bedding course, the breakage being much less on the former than the latter. The depth of the sand bedding course should not greatly exceed ¾ in. Increasing the depth tends to produce roughness in the pavement.
4. That cobbling of the brick is greatly increased as the spacing between bricks is increased.
5. That the use of excessive quantities of asphalt filler is a common and serious fault in construction, unnecessarily increasing the cost and resulting in a condition which impairs both the appearance and the serviceability of the pavement.
6. That base construction of other than the rigid type may in many cases prove entirely satisfactory. Macadam bases and those constructed of certain types of natural earth appear to be suitable when the local condition are such that these types of construction maintain their stability throughout the year.
7. That no difference in the base construction is necessary for the different thicknesses of brick.

Considering the fact that brick surfaces are an expensive type which can only be economically justified under heavy traffic it is most certainly desirable to use only the best of materials in the construction. The depth of the base should be amply strong when first constructed, as it is poor policy to take a chance on depth failure for this type. Materials, details of design, and inspection are outlined on page 508.

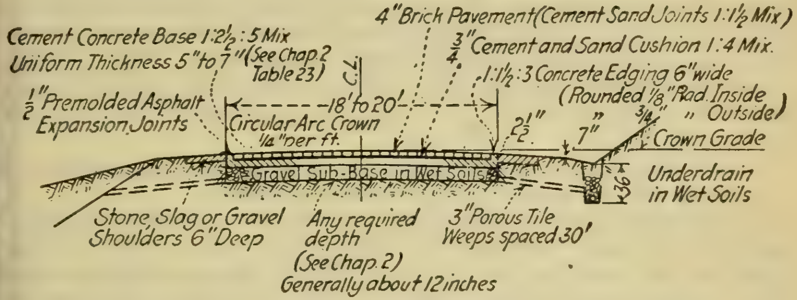
Brick-paving practice is going through a transition stage in the same way as concrete-paving practice, due to the radical difference in service demanded by modern motor traffic on rural highways as contrasted with the old horse-drawn vehicles, and any statement of recommended practice is tentative at best.

Recommended Designs.—The following designs can be used with an assurance of reasonable success. They represent conservative practice for localities having a gross vehicle-load limitation of 28,000 lb.

Suitable Materials.—Suitable materials for macadam and cement bases are the same as discussed under Macadam Pavement (pp. 429 to 449) and under Asphaltic-concrete Pavements (p. 492).

Brick (Size).—The size of standard paving block is usually specific as between 3¼″ wide, 3¾″ deep by 8½″ long and 3½″ wide by 4″ deep by 9″ long. For any particular size used on single

jobs, the maximum difference in depth should not exceed $\frac{1}{8}''$, in width $\frac{1}{8}''$, and in length $\frac{1}{2}''$. Kiln marks over $\frac{3}{64}''$ in height cause the rejection of individual brick. If the brick have rounded edges they should not exceed $\frac{3}{16}''$ radius (square brick are preferable where a cement-grout filler is specified). Wire-cut or pressed lugs on one side of the brick should produce a separation of the block of at least $\frac{1}{8}''$ and not over $\frac{1}{4}''$. This standard size produces a very effective and handsome pavement on village or city streets and on Class I traffic rural highways. There is, however, a growing need for a smaller unit for resurfacing worn-out



168*A*.—Recommended design (cement grout joints.)

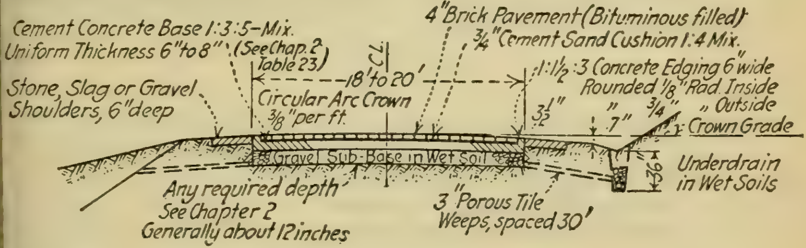


FIG. 168*B*.—Recommended design (bituminous joints).

macadam and concrete pavements, particularly on grades of more than 4% where asphaltic-concrete pavements are not entirely satisfactory because of the tendency of motors to skid in damp weather. Whether this need will be met by small stone blocks or by thin brick or brick cubes is still in doubt and will depend very largely on the general attitude of the stone-block and brick-paving manufacturers in producing an acceptable grade of cube at a reasonable cost. The standard 4" block is not only very clostly for such conditions but also introduces too much change in surface elevation, particularly where a contracted section in cut with gutter is used.

A considerable yardage of pavement constructed of brick of standard surface dimensions but with a 3" depth has been laid in an effort to reduce freight costs on the materials. There is considerable doubt as to the advisability of reducing depth dimensions where the width and length remain the same, as it unbalances

the resistance of the block, particularly over a macadam base, and for heavy-traffic roads this expedient may well be used with caution. Special-shaped, grooved blocks, known as hillside brick, are used on steep grades.

Quality.—Paving block are manufactured of special mixtures of clay or shale. Most pavers are a shale product, although very good brick can be manufactured by a well-controlled clay mixture. The essential qualities of the finished product are that the brick shall be well annealed, tough and evenly burned, and free from laminations, voids, and cracks. When broken, they must show a uniform, stone-like fracture. There are two general types, the wire-cut brick and the repressed brick. The consensus of opinion among engineers seems to favor the wire-cut method, as the brick is, perhaps, less likely to show laminations. The wire-cut block also has the square edge, which is desirable where cement grout is used as the joint filler, as there is less liability for the grout to chip out.

Where bituminous joint filler is used, a well-manufactured wire cut brick without lugs is generally specified.

All paving materials are subject to tests for toughness and absorption, and in some cases to the rupture test for cross-breaking, although the last test is hardly necessary for the standard-size block. Toughness is determined by the rattler test described on page 715. The maximum loss by abrasion in this test is usually set at 24% for heavy-traffic roads and the maximum absorption at 3½%. Modulus of rupture is to be not less than 2000 lb. per square inch computed by the formula

$$R = 3\frac{WL}{2bd^2},$$

in which R = modulus of rupture.
W = load in pounds which produces rupture.
L = length between supports (6″).
b = width of brick, in inches.
d = depth of brick, in inches.

Cushion Sand.—The plain sand cushion is going out of use in favor of either the cement-sand or bituminous-sand cushion. Where a sand cushion is used, it must be free from pebbles and fairly clean. A common specification calls for 100% passing a 6 sieve, 90% passing a 20 sieve, and not over 10% of loam or silt. Unsatisfactory portions of many brick pavements have been directly traceable to poor cushion and to careless manipulation, which resulted in the sand working up between the brick and preventing proper grout penetration.

Where the cement-sand cushion is used, a first-class concrete sand containing not over 8% of loam is required; the usual mix for this type of cushion is 1 part cement to 4 of sand, which gives the necessary stiffness to prevent flowing of the cushion.

Where bituminous-sand cushion is used, the sand should be a clean, coarse concrete sand mixed with about 4 to 6% of bitumen of the proper grade (see page 1399).

Grout Sand.—Must be a clean, sharp concrete sand containing not over 5% of loam or silt. A common specification requires 100% passing a 12 sieve and not over 40% passing a 50 sieve. A mixture of 1 part cement to 1 part grout is often specified. The National Brick Manufacturers recommend 1 part cement to 1½ parts sand.

Bituminous Filler.—Either asphalt or tar-pitch filler can be successfully used for Specifications (see page 1401).

Amounts of Materials.—The amounts of material for macadam bases are given under Macadam (p. 441), and for concrete bases on page 495.

Brick is usually purchased by the square yard finished pavement on account of culling, etc., so that the number of brick per square yard is of little value. In case brick is purchased by the 1000, the following table from Blanchard will be of use.[1] Ordinary standard paving block 3½ by 4 by 9″ lay about 40 to the square yard.

Size of brick	Number of brick per square yard ⅛″ joint
2¼ by 8 by 4 laid flat	67
2¼ by 8¼ by 4 laid edgewise	65
3¼ by 8½ by 4 laid edgewise	45
2½ by 8½ by 4 laid edgewise	57
3 by 9 by 4 laid edgewise	46

Grout.—One barrel of cement will grout approximately 36 sq. yd. of standard 4″ depth block with grout mixed 1:1.

Expansion Joints.—Premolded joints purchased by the linear foot are usually used. In case the joints are poured, 1 bbl. of paving pitch will fill approximately 130 lin. ft. of joint 1″ wide and 4″ deep.

Design.—Design covers selection of type of pavement (monolithic, semimonolithic, or rolled base), depth of base, type of brick surface (grouted or bituminous filled), type of cushion (cement sand, bituminous sand or plain sand), width, and crown of pavement.

Type.—As previously discussed, the semimonolithic on cement-concrete base is the type probably entitled to most consideration for heavy-traffic rural highways.

Depth of Base.—If a macadam base is used, the design of depth is quite definite, as discussed on page 391. If the cement-concrete type of base is used, any existing formula is speculative to say the least, and experience is the best guide. Experience can, however, be expressed in the form of tentative formulas, as developed on pages 421 to 427.

[1] BLANCHARD, "Highway Engineering."

Adequate depths of macadam base under heavy traffic depend on the foundation soil and range from 8 to 24″, using Formula (2), (p. 384), with a wheel load of 14,000 lb. (28,000-lb. gross static vehicle load) and assuming that a bituminous-filled brick top is equivalent to 2″ of macadam.

Adequate depths of cement-concrete bases depend on the richness of the mix of the concrete base, on whether the pavement is of the monolithic or semimonolithic type, and, if of the semimonolithic type, whether the surface is grout filled or has a bituminous filler.

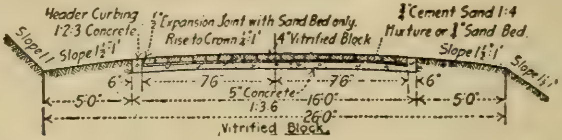


FIG. 169A.—Standard brick pavement. State of Pennsylvania (1922).

Current practice generally uses a 4″ depth of cement concrete with 4″ brick for the monolithic type, and for the semimonolithic type, with concrete ranging in mix from 1:3:6 to 1:2:4, the depth of base ranges from 5 to 8″ with slightly greater depth for bituminous-filled brick. Tentative formulas developed on page 421 indicate that for rural highway conditions (28,000-lb. gross vehicle load), using the recommended semimonolithic type with a base mix of 1:2½:5, a depth of 6 to 7″ for grout-filled surface and 7 to 8″ for bituminous-filled surface will be satisfactory.

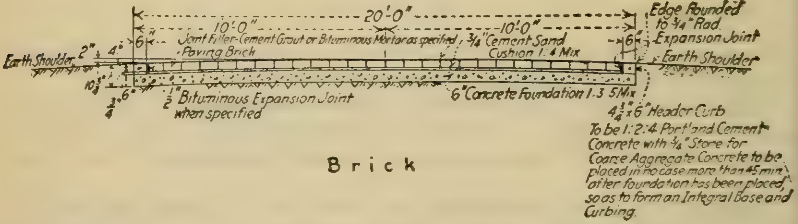


FIG. 169B.—Standard brick pavement. State of New Jersey (1922).

Expansion and Contraction.—Bituminous-filled brick surfaces do not require any special provision for temperature stresses.

Cement-grout-filled brick require longitudinal joints along curb or edging. Premolded bituminous strips are the best type of joint. A joint width on each side of ½″ is sufficient for rural roads up to 20′; for wider streets, 20 to 30′, ¾″ width; and for greater widths, 1″.

Transverse joints are rarely used and appear to be detrimental; infrequent blow-ups may better be permitted. Where these joints are used they are generally spaced at 50′ intervals and have a ½″ thickness.

Width and Crown.—Widths are the same as for any rigid rural pavement (pp. 130 and 6). Widening on curves is desirable. Where a state highway with a large volume of traffic passes through villages, 30′ is satisfactory for resident streets and 40 to 60′ for business streets. The crown usually used for 18 to 20′ rural roads is a circular arc, ¼″ per foot for grouted brick and ⅜″ per foot for bituminous filled; banking on curves is given (p. 127). Village-street crowns are indicated (p. 505). The straight-line crown is to be avoided, as discussed on page 474 (Concrete Pavements).

Steep Grades.—Hillside brick should be used on grades over 5% for grouted surfaces and on grades over 8% for bituminous-filled brick where horse traffic must be considered.

Specifications.—See Part III (p. 1476).

Equipment.—See Chap. XV.

Inspection Details.—See Chap. XVI (p. 1330).

General Maintenance Methods.—See Chap. VII (p. 569).

Asphalt-block Pavement

Asphalt-block pavements are an excellent type for extremely heavy Class I traffic, particularly where roads of this class pass through villages and the grades are not steeper than about 4%. The pavement shows a smooth, uniform surface, dustless, and practically noiseless. Its life probably lies between 15 and 20 years, depending on the quality of block. Failures that occur in shorter time are generally due to inferior block. The quality of block is important. A mist or light rain makes the pavement very slippery on grades of over 4%. Within a reasonable freight radius of the point of manufacture this pavement costs about the same as brick for original construction. It is used as a surfacing on both concrete and macadam bases. This type of pavement should be used with caution on macadam bases, as it is an expensive surface and its form is not so applicable to use on top of macadam as the sheet-asphalt type.

The asphalt-block pavement laid on New York State rural highways has been very satisfactory. The proportion of ingredients is about 70% crushed rock, usually trap, which has passed a ¼″ ring, about 20% limestone dust to act as filler, and approximately 10% of asphaltic cement, molded under a pressure of 2 tons per square inch of block having a 2″ depth This produces a dense asphalt much superior to the ordinary sheet. The asphalt used is Trinidad. This is refined and fluxed so that the resulting asphaltic cement may be varied as to adhesiveness, penetration, etc., to meet varying conditions peculiar to different localities. The penetration is made high enough to give a certain amount of pliancy to the block, to avoid crumbling at the edges, and to make the joints self-healing.

The use of blocks containing steel anchors, laid across the road approximately 15′ apart, has eliminated any movement of the block under traffic. These blocks are placed at more frequent intervals on curves. Block pavements have been laid, using a longitudinal row of these anchor blocks in place of edging. The

results appear satisfactory, although under these conditions it is probably desirable to thicken the base at the edge.

After the base is prepared a mixture of 1:4 Portland cement mortar is spread ½″ thick. This mortar bed is carefully screeded and the block laid thereon, joints being broken at least 4″.

An interesting comparison with brick occurs in the "pinning in" curbs. Instead of bats being broken by hand a large mechanical shear is used. Each fractional block is measured and cut to fit exactly.

After being laid, the pavement is given a light coat of sharp sand, which is broomed into the joints. Traffic is permitted in 4 or 5 days.

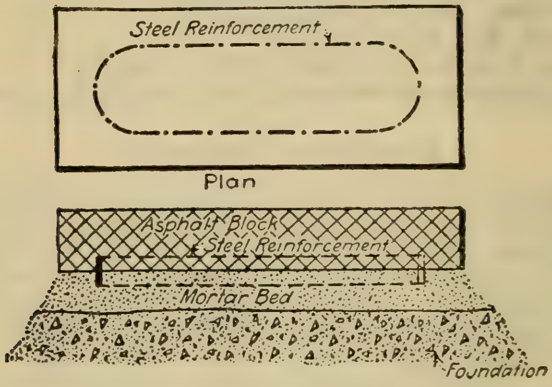


FIG. 170.—Anchor block detail.

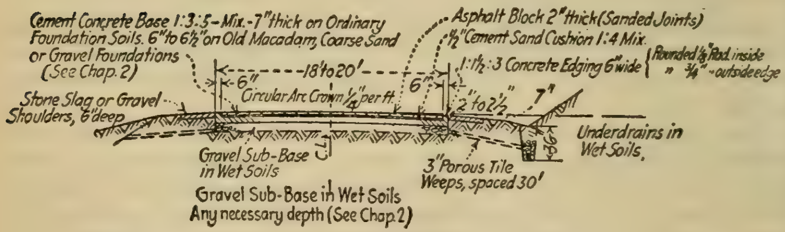


FIG. 171.—Recommended design asphalt block.

Advantages.—The pavement shows a smooth, uniform surface, dustless and practically noiseless. Its life on rural highways has yet to be determined. Pavements that have been down 10 or 15 years are still in good shape. Within a reasonable freight radius from the point of manufacture, it can be laid for approximately the cost of brick.

Disadvantages.—A mist or light rain makes the pavement very slippery. It should not be used on grades of over 4%.

Recommended Design.—The following recommended design is for conservative practice in localities having a gross vehicle-load limitation of 28,000 lb.

Suitable Materials.—Materials for concrete base are the same as discussed under Asphaltic Concrete (p. 492).

The block itself, being a manufactured product generally laid under a guarantee, cannot be too definitely described in a general specification. It is, perhaps, just as well to specify trap-rock stone aggregate where this is available, as such blocks apparently wear considerably better than the softer limestone blocks. Well-manufactured blocks using stone aggregate with a per cent of wear of 5 or less will probably be satisfactory; the consistency of the bituminous binder had better be left to the manufacturer so long as he understands the traffic and climatic conditions to be met. An example of the ordinary specifications is given page 1474.

Amounts of Materials.—Amounts for bases are the same as given under Asphaltic Concrete Pavements.

Design.—The design of base thickness, width, and crown is the same as for asphaltic concretes (p. 497).

Equipment and General Methods.—Brick-paving equipment and methods apply.

Inspection Details.—Inspection is essentially the same as for brick-pavement work.

Specifications.—See pages 1474 to 1476.

LESS-USED PAVEMENTS

The text on the following pavements is condensed, as they are at present used for comparatively small yardage under special conditions. The specifications give essentials (see page 1479).

Wood-block Pavements

Wood block can be rarely used to advantage on rural highways. In exceptional cases they can be considered. Specifications are given on page 1479.

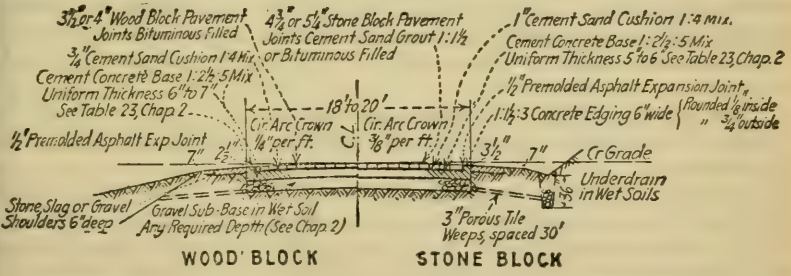


FIG. 172.—Recommended design. Stone and wood block.

Stone-block Pavements

Stone-block pavements, on account of their high first cost and somewhat irregular surface, are uncomfortable for high-speed traffic. They are generally specified on rural highways only on steep-grade Class I traffic roads where the normal pavement adopted is

too slippery for safety. For these conditions these pavements offer the best possible and most economic solution, considering service and final cost. Specifications are given on page 1481. The following recommended design is conservative practice for Class I roads.

Small Stone-block Surfacing.—In Germany, Hungary, Austria, and England a surfacing made of granite blocks, ranging in size from 2½″ to 4″, has been used successfully. This pavement is known as "Kleinpflaster" in Germany and as "Durax" armoring in England. The stone cubes must be cut with considerable accuracy in order to give a smooth and durable surface.

The blocks are laid on a thin sand cushion of about ⅜″ depth, on either a macadam or concrete foundation; they are thoroughly rammed to give a firm bearing and the joints filled with either clean

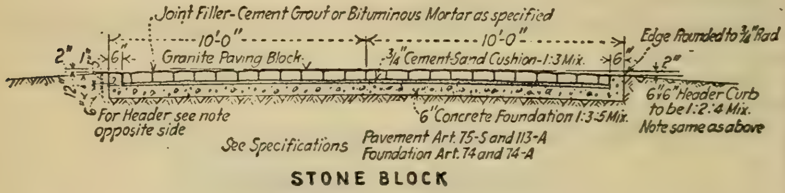


FIG. 173.—Standard section, State of New Jersey (1922).

sand flushed in or a bituminous filler. The joints do not exceed ¼″ in width. The courses of cubes are laid either diagonally to the direction of the traffic or in concentric rings.

Where the stone is broken by hand the cost is high, and it would be impossible to consider its use for rural roads in this country. A machine[1] has, however, been developed in Europe for breaking these cubes which is claimed to produce a satisfactory product at a reasonable rate. It is a belt-driven friction drop hammer having a stone chisel mounted on the anvil; the hammer head is shaped like a stonecutter's sledge. About 1½ hp. is needed for each machine.

About 400 of these machines are in operation, and a plant in Sweden is turning out 700,000 sq. yd. of pavement per year with 62 machines.

Provided the stone-cube surface, exclusive of base, can be laid for $3 to $4 per square yard, it seems a type that must be seriously considered on steep-grade Class I traffic, particularly for resurfacing old pavements under reconstruction programs. A price as low as this, however, would probably necessitate the use of convict labor in the manufacture of the cubes.

McClintock Cube Pavements

This is a patented pavement devised by J. Y. McClintock, County Engineer of Monroe County, New York. The patent has run out

[1] A detailed description of this machine is given in *Eng. News*, Mar. 27, 1912.

and it is available for use without the drawbacks of patent limitations. It is very similar to "Kleinpflaster," except that under his patent artificial cubes as well as stone cubes are proposed. It appears to be a very promising type.

The construction is essentially as shown in Fig. 174 and consists of a top course of 2¼″ cubes placed on a thin sand, cement-sand, or bituminous cushion supported by either a macadam or a concrete base. The cubes have been made of concrete, vitrified-paving-brick material, and stone as in Continental practice.

They are loaded, hauled, and dumped like broken stone; laid in close contact by means of a pallet and rake, 128 at a time on a sand cushion ¼ to ½″ thick, no care being taken to break joints. They are then rolled to bring to an even and firm bearing; the joints are filled with a sandy loam and the surface treated with a light coat of light road oil or cold tar if the foundation is macadam. The joints are grouted if the foundation is concrete. Temporary shoulders of 2″ plank are put down during the laying of the cubes, after which they are removed and replaced with broken stone or gravel as shown in Fig. 174.

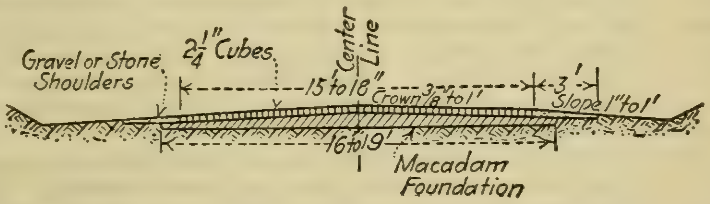


FIG. 174.—Typical section cube pavement on macadam base.

The experience of the past 13 years has shown that this form of construction using a sand-tarred joint is flexible under frost action, which makes it suitable as a surfacing on a macadam base. It keeps its shape under traffic and shows no tendency to ravel or break down at the edges, and can be successfully held with a macadam or gravel shoulder without the formation of a rut along the edge, which is a difficulty always encountered where a rigid edging is designed. It gives a satisfactory surface in both wet and dry weather and can be laid late in the season. The cubes require comparatively little inspection and can be successfully used as patches in maintenance with simple manipulations. They reduce the tonnage and freight cost where imported materials are required. The cubical form simplifies laying and makes a well-balanced block to resist rupture. This type is essentially the macadam type, with a perfect-shaped macadam unit, the cube. Concrete cubes have not served satisfactorily, failing in spots, but this is to be expected, as it is not a reliable material for a road surfacing of this nature (that is, for such small units). Vitrified-shale cubes with wide sand joints laid on a macadam base have shown ability to stand medium traffic. Vitrified-shale cubes with close tarred joints laid on a thick macadam base serve very satisfactorily under moder-

ately heavy traffic, and these cubes laid on a concrete foundation and grouted meet all but the heaviest traffic satisfactorily.

Consider briefly the present tendencies in highway construction. There are two distinct types: the flexible form, represented by the macadams, and the rigid types, such as brick, asphalt, stone block, etc., having concrete foundations. Each has a distinct field and their relative economy depends largely on the traffic.

It is sufficient for this discussion to note that macadams are suitable for light and medium traffic (Classes II and III), that they are able to withstand climatic changes better than the rigid pavements, and that with a moderate yearly expenditure they can be kept in good condition when used under the volume of traffic stipulated.

They fail either under high-velocity traffic or heavy hauling, the first being a surface failure and the second a foundation failure for most of the roads, but a surface failure for some which have a thick, well-consolidated base. That is, if some better flexible surface can be used on a first-class macadam foundation, this type of road will be able to handle a heavier volume of traffic than at present with a moderate maintenance charge. The indications are that the brick cubes with sand-oiled joints will serve this purpose.

The rigid roads develop defects due to temperature changes, frost heave, and the settlement of fills. Subsequent movement is localized along these lines, and eventually expensive repair and reconstruction is necessary. Under heavy traffic, however, the cost is less than for the macadam type and the inconvenience of continual repairs is avoided.

The first cost of standard rigid pavements is so high that designers often hesitate to use them where they are actually needed. If it were possible to reduce the cost and yet obtain practically the same class of improvement a larger mileage could be used to advantage.

The indications are that the brick cubes on a concrete foundation will serve this purpose at a cost considerably less than the present paving brick.

Highway designers do not hesitate to use macadam for the light traffic roads or expensive rigid constructions for the extremely heavy traffic; the great mileage that lies on the verge of either form of construction offers the real difficulty. It is for this class of road that the cubes are particularly adapted by reducing the cost of brick and increasing the efficiency of macadam. This applies also to the resurfacing of concrete and macadam roads which on steep grades is an annoying problem to the highway engineer.

It is believed that, provided this type fulfills its present indications, it will meet a recognized need in highway construction, particularly in reconstructive programs. For this reason more space than perhaps is justified has been given to a method which has not been tested out by a large-mileage construction.

This type of surface compares favorably in initial cost with asphaltic concretes. It is adaptable to manufacture by convict labor.

CHAPTER VII

MAINTENANCE

Maintenance is more a matter of business organization than of technical engineering knowledge. Reconstruction is primarily an engineering proposition (see Chap. VIII). Effective maintenance methods and the reasonable uses of different materials for repair have been quite well determined by practice. Existing flaws in maintenance practice are due largely to insufficient funds and political interference with the personnel of the maintenance organization. Of these two difficulties, lack of funds is the most serious. Funds are a legislative tax problem and a proper solution always lags behind the necessities of the situation. For years, engineers have warned legislative bodies that more adequate provision must be made for repair, but active steps to provide such funds have been slow in developing. This is natural, as it is difficult for a non-technical man to appreciate the necessity before he has some physical evidence to support the statement, and such evidence is only furnished by roads which have gone to pieces. Modern conveniences cost money, and no expedient has yet been devised to avoid "paying the piper." At the present time, the necessity for more adequate sums is receiving popular attention and support in states having improved systems of an average age of 10 years or more, and there is every indication that remedial action will be taken. Improved highways have demonstrated their worth so thoroughly that there is no danger of any community permitting them to continue permanently in poor condition. Reasonable legislative action depends on engineering estimates of maintenance and renewal costs.

MAINTENANCE AND RENEWAL COSTS

There are two general classes of estimate:

1. For drafting a general legislative tax program.
2. Yearly budget estimates.

The first type of estimate requires consideration of future conditions.

The second class states definitely the immediate requirements of the situation. The first class of estimate is subject to considerable uncertainty on account of fluctuating labor and material costs, change in traffic volume, spasmodic maintenance, control of truck loading and speed, etc., but a reasonably close approximation can be derived by an experienced maintenance man. The yearly budget estimates are an easy, definite problem, as they are based on actual physical evidence.

TABLE 97.—PROBABLE AVERAGE MAINTENANCE AND RENEWAL COSTS FOR DISTRICTS SIMILAR TO WESTERN NEW YORK

(COMPILED IN 1922)

(Computed for normal conditions. Exceptionally favorable conditions in regard to maintenance appropriations and personnel of the force might easily reduce maintenance and renewal costs 20 to 30%—see Table 105)

Type of pavement	Width, feet	Average depth, inches	Construction costs: Contract cost per square yard pavement only	Construction costs: 5% interest on cost	Yearly maintenance: Pavement only per square yard	Yearly maintenance: Shoulders, ditches, guard rail, etc.	Renewal[c]: Assumed normal life	Renewal[c]: Yearly cost for renewal	Total maintenance and renewal: Per square yard	Total maintenance and renewal: Per mile	Total interest on construction, maintenance, and renewal: Per square yard	Total interest on construction, maintenance, and renewal: Per mile
Column No. 1	2	3	4	5	6	7	8	9	10	11	12	13
Class I traffic (2000 or more vehicles daily 10-hr. count in summer)												
Stone block on concrete base	18–20	12	$5.50	$0.275	$0.005	$0.020	30–35	$0.100	$0.125	$1,400	$0.400	$4,400
Brick on concrete base	18–20	11	4.20	0.210	0.015	0.020	15–20	0.160	0.195	2,150	0.405	4,450
Asphaltic concrete on cement base	18–20	10	3.50	0.175	0.020	0.020	10–15	0.170	0.210	2,300	0.390	4,300
Reinforced cement concrete[a]	18–20	8	3.20	0.160	0.015	0.020	12–15	0.160	0.195	2,150	0.360	4,000
Penetration bituminous macadam[a]	18–20	13	2.50	0.125	0.070	0.020	5–9	0.200	0.290	3,200	0.420	4,600

Class II traffic (800–2000 vehicles daily 10-hr. count in summer)												
Reinforced cement concrete[a]	16–18	8	$3.20	$0.160	$0.010	$0.015	15	$0.145	$0.170	$1,700	$0.330	$3,300
Asphaltic concrete on macadam base	16–18	12	3.00	0.150	0.020	0.015	12	0.150	0.185	1,850	0.335	3,350
Brick cubes on macadam base	16–18	12	3.00	0.155	0.020	0.015	12	0.160	0.195	1,950	0.345	3,450
Penetration bituminous macadam	16–18	12	2.20	0.110	0.040	0.015	10	0.120	0.175	1,750	0.285	2,850
Water-bound macadam (oiled)	16–18	12	1.90	0.095	0.080	0.015	8	0.110	0.205	2,050	0.300	3,000
Class III traffic (300 to 800 vehicles daily 10-hr. count in summer)												
Penetration bituminous macadam	12–16	10	$1.90	$0.095	$0.030	$0.012	12	$0.100	$0.140	$1,100	$0.240	$1,900
Water-bound macadam	12–16	10	1.60	0.080	0.060	0.012	10	0.070	0.140	1,100	0.220	1,800
Class IV traffic (less than 300 vehicles daily)												
Water-bound macadam	8–12	9	$1.50	$0.075	$0.040	$0.012	12	$0.060	$0.110	$ 650	$0.180	$1,100
Gravel[b]	8–12	10	1.00	0.050	0.040	0.012	8	0.030	0.080	500	0.130	800

[a] These types eventually resurfaced with asphaltic concrete or some form of standard block or cube surface.

[b] This type can be temporarily used under heavy traffic, but for a volume of over 400 to 500 daily it generally develops disagreeable waves known as rhythmic corrugations.

[c] Based on maximum allowable roughness of 250″ per mile Vialog measure without exceeding normal maintenance expenditures.

Legislative Tax Estimates.—Reliable estimates of the future cost of maintenance and renewal depend more on personal knowledge and personal records of an experienced engineer than they do on the exact application of official published reports of maintenance costs. Students may well bear in mind that the usual official report on maintenance expenditure is a broad average, subject to misinterpretation due to inaccuracies of bookkeeping, inadequate strength of some of the pavements, spasmodic appropriations for maintenance, difference in age of pavements, difference in volume of traffic, etc. If due allowance is made for these factors, the values finally adopted often depart considerably from published figures.

Table 97 (p. 520) gives a basis for future cost estimates which can be used with assurance of reasonable accuracy for conditions similar to those in New York State. This is a conservative estimate, assuming average conditions of efficiency. If the roads are designed of adequate strength and are maintained under an unusually effective system of appropriation and personnel, the maintenance and renewal costs could probably be reduced about 20 to 30% (see Table 105, p. 536). The data were derived as follows:

In order to avoid needless inaccuracies as much as possible, this discussion is based on careful analysis of the records of Division 4, New York State Department of Highways, of which the author has personal knowledge, supplemented by general State Reports of New York and Massachusetts. The data are analyzed in two ways: (1) Reported average costs are modified for average conditions of age, strength, volume of traffic, and effectiveness of maintenance. This analysis gives a good basis for future estimates under prevailing conditions. (2) Typical individual roads are selected which are known to be adequate in strength and have received moderately good attention; the costs for these special roads are tabulated. This method indicates what can be done under good supervision with adequate funds. Division 4 is selected for analysis as it has been used throughout this book to illustrate the practical application of theories of finance, type selection, traffic volume, etc.

Yearly Costs per Vehicle Mile.—The Highway costs given in Table 97 expressed in terms of vehicle miles may be roughly approximated as follows:

TABLE 97*A*

Class of traffic	Assumed average daily volume	Average cost of maintenance and renewal per vehicle mile, cents	Average cost of interest maintenance and renewal per vehicle mile, cents
Class I	4000	0.2	0.3
Class II	1500	0.3	0.6
Class III	600	0.5	0.8
Class IV	200	0.7	1.4

The saving in traffic operation cost due to well-maintained, hard-surfaced roads is probably about 1 to 1.5 cts. per ton mile, which indicates that modern improved roads can probably be justified by economic travel return for volumes of traffic of over 300 daily, but that for traffic of less than this amount other more indirect benefits must be considered to justify hard-surfaced, year-round pavements (see Fig. 3, p. 16, Chap. I).

Basic Conditions, Division 4, New York State Department of Highways.—This division includes six counties in western New York having an area of 3600 sq. miles, an assessed valuation, 1920, of approximately $523,000,000, a total motor vehicle registration, 1920, of 58,000, and a total road mileage of 6700 miles. At present there are 870 miles of state-improved roads under maintenance and the following analysis is based on official cost reports for this mileage, modified by personal knowledge of conditions. The executive personnel of this division has been excellent; it is as free from objectionable political interference as any locality is likely to be. There is no great frequency of overloaded truck traffic. The main difficulty has been lack of adequate funds. Table 98 shows at a glance that, due to lack of funds and average age, the maintenance costs as reported must be modified if used as a basis for long-time legislative programs. Table 97 shows the necessary modified values.

Independent Check on Essential Correctness of Table 97 for Legislative Estimate Purposes.—Table 97 was built up from a detailed study of yearly maintenance figures and records of pavement durability. In order to check these results, the following test was made approaching the problem from an entirely different angle based on independent data. The essential agreement of the two methods indicates that the statistics given in Table 97 provide a safe basis for territory similar to western New York. The following tabulation and footnote are self-explanatory.

Tabular Comparison of Reasonable Estimated Requirements for Maintenance and Renewal Based on Table 97 (Class II Traffic) as Compared with Actual Appropriation Expenditures

(Division 4, New York state highways, average traffic conditions Class II)

Year	Miles of road under maintenance	Table 97 normal requirements per mile per year	Estimated normal yearly requirements, Table 97	Actual appropriations for maintenance and renewal
1914[1]	510	$1,100	$ 600,000	$ 360,000
1915[1]	590	1,200	700,000	376,000
1916[1]	660	1,300	900,000	330,000
1917	690	1,600	1,100,000	606,000
1918[2]	720	1,700	1,200,000	1,071,000
1919	750	1,800	1,400,000	674,000
1920	780	1,900	1,500,000	874,000
1921	840	1,800	1,500,000	1,080,000
1922	860	1,800	1,600,000	1,200,000
Totals	...	....	$10,500,000	$6,571,000

[1] Table 97 modified for prewar price scale.

[2] Emergency war appropriation (army-truck damage).

This table indicates that in 8 years actual appropriations have lagged behind reasonable upkeep requirements $4,000,000.

Table 98 (p. 526) shows that in January, 1923, the reconstruction program for worn-out surface is 7 years behind normal renewal for water-bound and 4 years behind normal renewal for bituminous macadams, and that to bring the system up to reasonable standard 300 miles should be immediately resurfaced. Such work will cost approximately $14,000 to $22,000 per mile, or a total of approximately $5,000,000, which checks the deficit in appropriations obtained by the application of Table 97 to this district.

The data are analyzed (pp. 523 to 534) for effect of strength, age, and traffic volume. The use of Table 97 in connection with legislative tax estimate (Division 4) is illustrated for the benefit of the student on page 20, Chap. I.

Analysis of Maintenance Costs. *Traffic Classification* (Table 99).—The basic factors of maintenance costs are volume and character of traffic. Table 99 classifies the roads by a study of the short-time traffic counts modified by common sense for future traffic growth (see p. 528).

Class I traffic—2000 or more vehicles daily (10-hr. count in summer).

Class II*A* traffic—1500–2000 (10-hr. count in summer).

Class II traffic—800–1500 (10-hr. count in summer).

Class III traffic—300–800 (10-hr. count in summer).

The outstanding conclusions from Table 99 are as follows:

1. The maintenance data on the macadam types for this district should be fairly conclusive, as there is enough mileage at a great enough age to mean something.

2. The maintenance cost for the rigid types is not yet at all conclusive and is probably far under normal, considering age and traffic volume.

3. Water-bound macadams are in the main, serving slightly more traffic than is recommended for this type.

4. Bituminous macadam is apparently serving about the proper volume for this type.

5. Cement concrete is serving considerably less volume than is recommended for this type.

6. Brick is serving somewhat less volume than is desirable for this type.

7. Stone block has been selected for footing on steep hills. Volume of traffic has no bearing.

8. Asphaltic concretes are, in the main, serving somewhat less than a reasonable volume of traffic for this type.

Strength of Existing Pavements, Division 4.—According to the best judgment of the engineering force in the division, based on observation of the resistance of the existing pavements to traffic action, the strength of the different types may be classed as follows:

Water-bound macadam, noticeably weak due to a large mileage of old, thin roads.

Bituminous macadam, moderately good due to a larger per cent of more recent design.

Asphaltic concretes on macadam, moderately good.

Asphaltic concretes on concrete, adequate with a few exceptions.

Cement concrete (1:2:4 mix or better), slightly low.

Brick on concrete, adequate.

Stone block on concrete, adequate.

These results appear in column 3, Table 98 (p. 526).

Recent designs which approximate the recommended depths developed in Chap. VI seem adequate for traffic.

Effect of Traffic Volume.—Records in this regard are meager. Table 100 (New York State) shows a start along these lines, but the figures are not very convincing, as records of soil conditions, adequate original strength, and relative age of pavements are not considered and the finance bookkeeping methods were not devised with the idea of enough subdivisions to give extremely accurate records for a tabulation of this kind. It is therefore necessary to use considerable judgment in assigning rational values to this factor of cost. According to the best judgment, a conservative set of yearly maintenance costs under different volumes of traffic for the most used types is given in Tables 97 and 98. One of the outstanding features of Table 100 is the high cost of shoulder maintenance on Class I traffic, indicating that 16′ width of pavement is poor economy under such traffic.

TABLE 98.—BASIC CONDITIONS DIVISION 4, JANUARY, 1923—MAINTENANCE COSTS (RENEWAL COST NOT CONSIDERED) (*Compiled by W. G. Harger for illustrative purposes*)

Type of pavement	Total mileage (1)	Physical modifying conditions: Average traffic conditions (2)	Actual pavement strength (3)	Actual average age, years (4)	Estimated reasonable average age for completed system provided renewals were properly made (5)	Per cent mileage needing resurfacing at present (6)	Normal yearly per cent resurfacing, long-term basis (7)
Gravel	5	Class III −	Adequate	6.1	5 years Class III (minus)	44	10
Water-bound macadam[a]	370	Class II −	Low	8.3	5 years Class II (minus)	70	10
Penetration bituminous macadam	244	Class II	Moderate	8.0	6 years Class II	35	8
Asphaltic concretes (macadam base)	25	Class II +	Moderate	5.0	6 years Class II	5	8
Asphaltic concretes (concrete base)[b]	36	Class I −	Adequate	6.6	7 years Class I	20	7
Cement concrete (1:2:4 mix or better)	124	Class II +	Moderate	2.4	7 years Class II (plus)	1	7
Cement concrete (1:2½:5 mix)	20	Class II	Moderate	5.0	3 years Class II	100	16
Brick (concrete base)	25	Class I	Adequate	7.5	9 years Class I	0	6
Stone block (concrete base)	2	Class II	Adequate	6.5	15 years Class II	0	3
Brick cubes (macadam base)	10.3	Class II	Low	13.0	7 years Class II	100	7

Column 5 is one-half of normal life which expresses normal conditions for average age figures.

$$\text{Column 7} = \frac{100}{\text{Normal life}}.$$

NOTE.—The outstanding feature of this tabulation is the large percentage needing resurfacing, which shows that the funds for renewals have been consistently inadequate and that ground is being lost each year, as regards the general condition of the system.

[a] Columns 3 to 7 would indicate that the reported maintenance cost should be high for water-bound macadam. As a matter of fact actual expenditures are low, as the maintenance budget estimates are consistently reduced below the amount required, as the funds are short. The main roads are given preference and the water-bound type (largely on secondary roads) have to get along with less expenditure than they are entitled to.

[b] The large per cent requiring renewal at a short age is due to poor original construction (overburned mix).

TABLE 98—*Continued*

Type of pavement	Effect physical conditions shown in columns 2 to 7 should have on necessary costs (8)	Approximate average cost maintenance pavement per year (5-year average) (9)		Remarks	
		Per mile	Per square yard	Adequacy of actual expenditures (10)	Finally adopted actual relation of reported maintenance costs to normal long-time condition, considering existing appropriation limitations as well as physical conditions prevailing
Gravel	High	$500	$0.065	Low	Normal
Water-bound macadam[a]	High	580	0.065	Low	Normal (minus)
Penetration bituminous macadam	High	400	0.043	Slightly low	Normal (plus)
Asphaltic concretes (macadam base)	Normal (minus)	120	0.012	Adequate	Normal (minus)
Asphaltic concretes (concrete base)[b]	Normal (plus)	160	0.017	Adequate	Normal
Cement concrete (1: 2: 4 mix or better)	Very low	40	0.004	Adequate	Very low
Cement concrete (1: 2½: 5 mix)	High	450	0.048	Low	Normal
Brick (concrete base)	Normal (minus)	80	0.009	Adequate	Normal (minus)
Stone block (concrete base)	Very low	75	0.008	Adequate	High
Brick cubes (macadam base)	High	300	0.032	Low	High

TABLE 99.—APPROXIMATE MILEAGE AND AGE UNDER DIFFERENT TRAFFIC CLASSIFICATIONS, DIVISION 7, JANUARY, 1923

Traffic classification	Total miles	Average age	Mileage at different ages, years (January, 1923)																				
			0	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	20	21
Gravel pavement (bituminous seal coat)																							
Class I																							
Class IIA																							
Class II																							
Class III	5.3	6.1	....	....	....	....	....	2.4	....	2.9													
Water-bound macadam (bituminous seal coat)																							
Class I	4.5	12.7	....	....	....	....	1.0	....	....	....	....	....	0.2	....	2.0	....	....	....	....	....	....	....	1.3
Class IIA	51.5	8.5	....	....	....	....	5.5	5.3	9.3	10.0	....	....	1.0	....	15.1	3.5	0.3	1.5	....	....	....	....	....
Class II	177.3	8.4	....	....	8.9	0.3	17.3	12.0	21.9	21.5	17.9	....	14.4	10.3	5.2	11.4	16.9	13.5	4.5	....	....	1.3	
Class III	158.3	7.1	23.3	3.3	....	11.6	3.4	10.4	24.3	20.3	15.5	....	0.5	2.7	10.5	18.2	7.9	2.7	3.7				
Penetration bituminous macadam																							
Class I	33.9	7.9	....	....	....	0.2	8.9	3.6	1.9	....	3.2	....	8.8	....	7.3								
Class IIA	45.8	8.0	....	....	0.4	2.6	10.6	....	1.0	1.4	0.8	1.4	12.1	10.5	5.0								
Class II	105.6	7.7	12.6	3.0	2.7	5.4	1.2	3.4	3.6	8.2	11.5	8.2	1.2	28.8	14.1	1.7							
Class III	52.9	9.0	....	0.3	....	0.5	2.7	1.2	3.4	1.4	....	19.2	11.6	8.7	2.2	1.7							
Asphaltic concrete, macadam base (total mileage not entirely covered in this table)																							
Class I	4.1	7.5	....	0.2	....	....	0.5	0.8	....	1.5	....	....	....	....	1.1								
Class IIA	9.6	5.0	....	0.3	0.7	2.4	....	4.6	....	0.6	....	0.1	....	...	0.9								
Class II	2.8	6.8	....	0.9	....	....	....	0.8	....	....	....	....	....	....	1.1								
Class III	0.6	3.0	....	0.4	....	....	....	....	0.2														
Asphaltic concrete, concrete base																							
Class I	8.5	6.4	....	....	2.3	1.1	....	....	....	0.7	1.4	....	3.0										
Class IIA	12.9	5.0	....	3.6	....	....	....	4.1	1.4	....	....	3.8											
Class II	5.9	8.0	....	0.3	....	....	....	....	1.0	....	....	4.6											
Class III	10.9	9.0	....	....	....	....	....	....	....	....	....	10.9											

Cement concrete, 1: 2: 4 mix or better																							
Class I.......	9.5	3.0	....	1.6	2.6	....	3.1	2.1															
Class IIA.....	38.5	4.0	1.1	15.6	....	0.3	....	9.0	....	....	12.5												
Class II......	31.8	1.0	2.1	20.7	6.3	2.7																	
Class III.....	35.0	1.4	3.4	22.5	1.5	4.2	3.4																
Brick on concrete base																							
Class I.......	8.7	8.0	....	....	....	....	....	1.0	0.1	1.7	3.1	2.4	....	....	0.4								
Class IIA.....	6.1	7.5	....	....	....	....	....	....	1.1	2.0	2.6	0.2	0.2										
Class II......	6.1	8.0	....	....	....	....	....	....	0.6	....	4.6	....	....	....	....	....	0.9						
Class III.....	1.8	8.0	....	....	....	....	....	....	0.6	....	0.6	0.6											

TABLE 100.—TABLES SHOWING AVERAGE COST OF MAINTENANC[E] OF VARIOUS TYPES OF PAVEMENT CLASSIFIED ACCORDING TO THE AMOUNT OF TRAFFIC

(1918 to 1922 inclusive New York State)

Amount of traffic per 12-hr. day, summer months	Miles	Cost of maintenance per mile per year	
		Pavement only	Total maintenance
Gravel pavement			
Less than 500	110.76	$584	$737
500–1000	31.49	721	924
1000–2000	6.62	675	872
Over 2000	0.60	824	983
Total	149.47 Average	$622	$785
Water-bound macadam			
Less than 500	1111.72	$551	$658
500–1000	763.26	652	843
1000–2000	360.12	692	897
Over 2000	38.51	881	1110
Total	2273.61 Average	$615	$766
Bituminous macadam, penetration method			
Less than 500	947.41	$303	$429
500–1000	1050.61	355	499
1000–2000	798.03	409	612
Over 2000	317.09	646	889
Total	3113.14 Average	$382	$547
Mixed bituminous macadam on macadam base			
Less than 500	12.87	$375	$473
500–1000	5.90	513	612
1000–2000	7.48	302	484
Over 2000	17.89	544	913
Total	44.14 Average	$449	$673
Mixed bituminous macadam on concrete base			
Less than 500	7.66	$ 99	$300
500–1000	22.65	146	231
1000–2000	30.39	146	298
Over 2000	29.02	229	336
Total	89.72 Average	$169	$293
Hassam pavement and second-class concrete			
Less than 500	47.79	$532	$759
500–1000	84.71	495	675
1000–2000	57.97	545	768
Over 2000	21.88	474	728
Total	212.35 Average	$517	$724

TABLE 100—*Continued*

Amount of traffic per 12 hr. day, summer months	Miles	Cost of maintenance per mile per year	
		Pavement only	Total maintenance
Brick pavement			
Less than 500	31.35	$165	$414
500–1000	64.33	99	199
1000–2000	62.69	109	219
Over 2000	87.77	279	493
Total	246.14 Average	$174	$337
First-class concrete pavement 1:2:4 or better			
Less than 500	114.61	$ 62	$172
500–1000	158.28	54	152
1000–2000	199.46	76	226
Over 2000	98.28	149	402
Total	570.63 Average	$ 80	$230
Total of above types			
Less than 500	2384.17	$422	$543
500–1000	2181.23	438	595
1000–2000	1522.76	422	618
Over 2000	611.04	495	735
Total	6699.20 Average	$433	$595

Life of Pavements. Macadam Pavements.—Division 4 data on rability of these pavements are reliable. Table 101 gives the e at which actual reconstruction has occurred. This table is teresting but not conclusive, as the records apply to the weaker ads under exceptional traffic which tends to shorten the age ported. On the other hand, these roads were permitted to remain poor condition for from 2 to 4 years beyond the time at which ey actually needed resurfacing. These data give the average age water-bound macadam as 8.9 years and bituminous macadam 8.4 years, Topeka on concrete at 7 years, and second-class conte (1:2½:5 mix) as 6.5 years. These results are inconclusive less verified by supplementary data.

Table 102 gives the mileage of the different types which need surfacing at their present reported age. These data are fairly iable in determining range of life and probable maximum. cording to these tables, supplemented by judgment in regard to odifying conditions, the reasonable life of the macadam base vements is placed as follows: (Table 103 p. 534).

These ages are somewhat less than usually adopted, since they based on a maximum permissible Vialog coefficient of roughss of 250′ per mile without excessive yearly maintenance expendes (see pp. 545 to 552). This limit of roughness is somewhat

TABLE 102.—APPROXIMATE PERCENTAGE OF MILEAGE WHICH NEEDS RESURFACING AT DIFFERENT AGES

Present age in years, January, 1923	Water-bound macadam		Penetration bituminous macadam		Asphaltic concrete on macadam base		Asphaltic concrete, concrete base		Second-class concrete		Gravel	
	Total miles at each age (column 1)	% of column 1 which needs resurface	Miles	%	Miles	%	Miles	%	Miles	%	Miles	%
1	26.3	0	15.9	0	1.8	0	3.9	0				
2	8.9	0	3.1	0	0.7	0	2.3	0				
3	11.9	0	8.7	0	2.4	0	1.1	0				
4	27.2	11	23.4	0	0.5	0	....	..	0.3	0		
5	27.7	30	8.2	6	6.2	30	4.1	25	1.66	100	2.4	100
6	55.5	25	9.9	20	0.2	0	2.4	0				
7	51.8	50	11.0	35	2.1	0	0.7	0	8.38	100	2.9	0
8	33.4	60	15.5	24	...	..	1.4	0				
9	....	...	28.8	30	...	..	19.3[1]	75	6.36	100		
10	16.1	100	33.7	30	...	..	3.0	0	4.14	100		
11	13.0	100	48.0	68								
12	32.8	100	28.6	78	3.1	30						
13	33.1	100	3.4	50								
14	25.1	100										
15	17.7	100										
16	8.2	100										
17												
18												
19												
20	1.3	100										

Modifying conditions and conclusions.	Average traffic Class II pavements rather weak considering soil and traffic. Range in durability, 4 to 10 years. Reasonable life for Class II for well-designed road probably 8 to 10 years.	Average traffic Class II pavements a little under adequate strength. Range in durability, 6 to 15 years. Reasonable life for Class II traffic well-designed pavements probably 10 to 12 years.	Average traffic Class I. *Data not conclusive.*	Poor construction. [1]Overburned mixture. *Data not conclusive.*	Class II traffic. Poor type of pavement. Reasonable life less than 5 years.	*Data not conclusive.*

less than has heretofore been customary, but it seems certain that on the main roads it is desirable to avoid the extreme roughness often tolerated for the last 3 to 5 years before reconstruction is commonly resorted to. The age, before reconstruction, can be increased by excessive maintenance expenditures, but this has little effect on the total cost of the combined items of maintenance and renewal; what is spent on one is saved on the other.

TABLE 101.—SHOWING AGE AT TIME OF ACTUAL RECONSTRUCTION

Age in years	Water-bound macadam			Bituminous macadam, penetration method			Bituminous macadam, mixing method, concrete base			Second-class concrete and Hassam concrete		
	Total resurfacing = 173 miles			Total resurfacing = 43.6 miles			Total resurfacing = 1.22 miles			Total resurfacing = 20.46 miles		
	Mileage rebuilt	Percentage of total	Accumulated percentage of total	Mileage rebuilt	Percentage of total	Accumulated percentage of total	Mileage rebuilt	Percentage of total	Accumulated percentage of total	Mileage rebuilt	Percentage of total	Accumulated percentage of total
3	0.30	0.2	0.2	....	....	....	....	....	....	0.65	3.2	3.
4	20.86	12.1	12.3	2.28	5.2	5.2	....	....	....	4.29	21.0	24.
5	5.94	3.4	15.7	0.77	1.8	7.0	....	....	....	3.53	17.2	41.
6	16.13	9.2	24.9	5.13	11.8	18.8	0.40	32.8	32.8	1.14	5.6	47.
7	13.80	8.0	32.9	8.81	20.2	39.0	....	....	....	2.31	11.3	58.
8	22.33	12.9	45.8	7.55	17.3	56.3	....	....	....	5.62	27.4	85.
9	26.90	15.6	61.4	2.92	6.7	63.0	0.82	67.2	100.0	1.92	9.4	95.
10	15.05	8.7	70.1	2.81	6.4	69.4	....	....	....	1.00	4.9	100.
11	19.74	11.4	81.5	11.21	25.7	95.1						
12	4.44	2.6	84.1	2.12	4.9	100.0						
13	11.48	6.5	90.6									
14	9.46	5.5	96.1									
15	2.38	1.4	97.5									
16												
17	2.15	1.2	98.7									
18												
19	2.20	1.3	100.0									

TABLE 103.—TABLE OF ESTIMATED REASONABLE LIFE, FLEXIBLE BASE PAVEMENTS

	Water-bound macadam	Bituminous macadam	Asphaltic concrete on macadam base
Class I traffic.......	Not suitable	6–12 years	8–14 years
Class II traffic.......	8–12 years	10–13 years	10–15 years
Class III traffic.......	10–13 years	12–15 years	Not advised
Class IV traffic[1].......	12–15 years	Not advised	Not advised

[1] Class IV is a very indefinite condition.

Table 97 uses the low limit. Under really good conditions of design and maintenance the upper limit can be used and even extended a few years.

Rigid-base Pavements.—The durability of rigid-base pavements on heavy-traffic rural highways cannot be very definitely settled as yet, as there are not enough miles of sufficient age to develop reliable data. Rural highway conditions are considerably different from city-street conditions due to concentration of traffic along an unprotected pavement edge and poor subsoil drainage systems on rural roads. City records are not really up to date on account of changed traffic conditions, so that the life assigned to rigid-base pavements is at best a careful guess which is controlled by the excellence of construction and maintenance practice for the district under consideration. The values assigned in Table 97 represent the best judgment of our local engineers reinforced by city records, and are for moderately good construction and maintenance conditions. The effect of good work on life is shown graphically on page 546. Supporting data are included below by a quotation from Blanchard's "Handbook."

TABLE 104.—CONSENSUS OF OPINION OF CANADIAN ENGINEERS AS TO DURABILITY (11)[1]

Pavement	Small repairs, years	Extensive repairs, years	Complete reconstruction, years
Asphalt block	5–10	10–12	12–15
Asphalt concrete	4– 6	6– 8[a]	8–10[a]
Bitulithic	5– 8	10–15	15–20
Brick	8–10	10–15	15–18
Cement concrete	5– 8	10–12	15–18[a]
Scoria block and stone	10–15	15–20	20–30
Sheet asphalt	4– 8	10–15	15–18
Untreated wood block	3– 5	6–10	10–12
Treated wood block	8–10	12–15	15–18[a]

[1] "American Highway Engineer's Handbook," John Wiley & Sons, Inc., New York.

[a] These pavements have not attained an age in Canada sufficient to place the figures beyond conjecture.

OPINIONS OF CANADIAN ENGINEERS AS TO NATURE OF DETERIORATION 11[1]

"*Asphalt block.*—Edge-wear forming holes and cobbles; worn pavement noisy and hard to keep clean; disintegration of bottom of blocks.

"*Asphaltic Concrete.*—Wears in holes; susceptible to marking in hot, sunny weather.

"*Bitulithic.*—Wears evenly, with a tendency to holes under heavier traffic susceptible to surface marks in hot weather.

"*Brick.*—Edge-wear and cobbling under heavy traffic; increased noise and unsanitariness as wear increases; when worn badly it slows down traffic.

"*Sheet-asphalt.*—Wears slowly into large holes or patches; heavy traffic causes ruts; cracks hasten deterioration.

"*Wood Block.*—Rots rapidly if untreated, retarding traffic; treated block wears slowly and evenly; frost intrusion causes buckling.

"*Stone and Scoria Block.*—Wears gradually into holes and cobbles; unsanitary when roughened.

"*Cement-concrete.*—Wear is slow and even, if well placed; cracking and chipping develop otherwise."

TABLE 105.—SELECTED ROADS. AVERAGE MAINTENANCE COSTS PER YEAR FOR A PERIOD OF 4 TO 5 YEARS (1918 to 1922)

(Renewal costs not included, as none of these roads have yet been resurfaced)

Road No.	Type	Traffic classification	Age, years	Foundation strength	Length, miles	Width, feet
61	Water-bound macadam—oiled	Class I	21	Adequate	1.30	16
810	Water-bound macadam—oiled	Class IIA	8	Adequate	1.03	16
648	Water-bound macadam—oiled	Class IIA	7	Adequate	7.37	16
403	Water-bound macadam—oiled	Class III	14	Adequate	2.07	14
492	Water-bound macadam—oiled	Class III	11	Poor	5.75	16
5507	Water-bound macadam—oiled	Class III	7	Adequate	2.14	16
1290	Water-bound macadam—oiled	Class III	7	Poor	1.53	12
5021	Penetration bituminous macadam	Class I	12	Adequate	3.98	16
5046	Penetration bituminous macadam	Class IIA	11	Moderate	5.75	16
62	Penetration bituminous macadam	Class IIA	10	Adequate	6.15	16
495	Penetration bituminous macadam	Class II	10	Adequate	6.15	16
5271	Penetration bituminous macadam	Class II	8	Weak	5.51	16
502	Penetration bituminous macadam	Class III	10	Adequate	5.20	14
80	Penetration bituminous macadam	Class III	13	Weak	3.60	16
63	Asphaltic concrete—macadam base	Class I	7	Moderate	1.50	16
253	Asphaltic concrete—macadam base	Class IIA	5	Adequate	0.75	16
5	Asphaltic concrete—macadam base	Class I	12	Adequate	1.07	16
5	Asphaltic concrete—cement-concrete base	Class I	8	Moderate	1.39	16
538	Asphaltic concrete—cement-concrete base[a]	Class I	10	Moderate	3.40	16
5302	Asphaltic concrete—cement-concrete base	Class IIA	5	Adequate	3.88	16
634	Asphaltic concrete—cement-concrete base[a]	Class II	9	Moderate	3.22	15
5279	Asphaltic concrete—cement-concrete base	Class III	9	Weak	6.14	16
1328	Asphaltic concrete—cement-concrete base	Class I	7	Adequate	0.73	16

5421	Cement concrete—1:2:4 mix or better	Class IIA	8	Adequate	0.80	16
5425	Cement concrete—1:2:4 mix or better	Class IIA	8	Moderate	3.24	16½
5423	Cement concrete—1:2:4 mix or better	Class II	8	Adequate	6.92	16
6	Cement concrete—1:2:4 mix or better	Class I	5	Adequate	1.54	16
5469	Cement concrete—1:2:4 mix or better	Class IIA	5	Adequate	8.95	16
1499A	Cement concrete—1:2:4 mix or better	Class III	1	Moderate	4.56	16
172	Brick on concrete base (cement-grouted joints)	Class I	7	Adequate	0.66	16
401	Brick on concrete base (cement-grouted joints)	Class IIA	14	Adequate	0.86	16
6	Brick on concrete base (cement-grouted joints)	Class I	8	Adequate	0.32	16
5435	Brick on concrete base (cement-grouted joints)	Class I	8	Adequate	0.94	16
1430	Brick on concrete base (cement-grouted joints)	Class I	5	Adequate	1.33	16

[a] Poor asphaltic mix on construction.

TABLE 105—*Continued*

Road No.	Type	Cost per mile, shoulders	Cost per mile, pavement	Cost per square yard, pavement	Remarks
61	Water-bound macadam—oiled	$ 25	$585	$0.062	Needs reconstruction
810	Water-bound macadam—oiled	198	308	0.033	Perfect condition
648	Water-bound macadam—oiled	94	284	0.030	Good condition
403	Water-bound macadam—oiled	52	434	0.053	Good condition
492	Water-bound macadam—oiled	35	250	0.027	Poor condition
5507	Water-bound macadam—oiled	71	379	0.040	Good condition
1290	Water-bound macadam—oiled	152	397	0.057	Fair condition
5021	Penetration bituminous macadam	139	335	0.035	Good condition
5046	Penetration bituminous macadam	198	350	0.037	Moderately good
62	Penetration bituminous macadam	55	227	0.024	Good condition
495	Penetration bituminous macadam	38	119	0.013	Good condition
5271	Penetration bituminous macadam	80	435	0.046	Fair condition
502	Penetration bituminous macadam	159	119	0.014	Good condition
80	Penetration bituminous macadam	27	164	0.018	Poor condition
63	Asphaltic concrete—macadam base	115	139	0.015	Good condition
253	Asphaltic concrete—macadam base	495	0	0.0	Excellent condition
5	Asphaltic concrete—macadam base	90	80	0.009	Good condition
5	Asphaltic concrete—cement-concrete base	152	127	0.013	Fair condition
538	Asphaltic concrete—cement-concrete base[a]	60	459	0.050	Fair condition
5302	Asphaltic concrete—cement-concrete base	366	172	0.018	Excellent condition
634	Asphaltic concrete—cement-concrete base	20	157	0.017	Poor condition
5279	Asphaltic concrete—cement-concrete base	26	183	0.019	Poor condition
1328	Asphaltic concrete—cement-concrete base	0	75	0.008	Good condition

5421	Cement concrete—1:2:4 mix or better	110	151	0.016	Excellent condition
5425	Cement concrete—1:2:4 mix or better	89	30	0.003	Fair condition
5423	Cement concrete—1:2:4 mix or better	128	8	0.001	Good condition
6	Cement concrete—1:2:4 mix or better	52	70	0.007	Good condition
5469	Cement concrete—1:2:4 mix or better	58	27	0.003	Good condition
1499A	Cement concrete—1:2:4 mix or better	22	10	0.001	Good condition
172	Brick on concrete base (cement-grouted joints)	112	56	0.006	Good condition
401	Brick on concrete base (cement-grouted joints)	56	56	0.006	Fair condition
6	Brick on concrete base (cement-grouted joints)	0 Village	131	0.013	Good condition
5435	Brick on concrete base (cement-grouted joints)	0 streets	79	0.008	Good condition
1430	Brick on concrete base (cement-grouted joints)	0 curbed	54	0.006	Good condition

Selected Typical Roads.—The second method of deriving normal costs is the selected-road method. Table 105 gives an idea of what can be done if the roads are well designed and maintained as compared with weak design and spasmodic maintenance.

Table 105 shows that firm water-bound macadam can be maintained under Class I traffic for about 6 cts. per square yard per year exclusive of renewals; under Class II traffic, for about 3.5 cts., but that weak design under even Class III traffic will raise the maintenance to about 6 cts.

Firm bituminous penetration can be maintained under Class I for 3.5 cts. for a long term of years (see road 5021); under Class II traffic for about 1.5 to 3 cts., but if the foundation is weak it jumps up to around 4.5 cts. (road 5271).

Asphaltic concretes on firm macadam base under Class IIA traffic have been maintained for a long term for from 0.9 to 1.5 cts. per square yard per year exclusive of renewals. The maintenance cost for these roads is about the same as for the same surface on a cement-concrete base.

The data on cement concrete and brick are not conclusive because of the short age of pavements on which definite data exists in comparison with their probable life. During 1925 the maintenance on concrete roads rose from $80 to $230 per mile for pavement alone or 2.3 cts. per square yard average for the division as a whole.

Budget Estimates.—Budget estimates are desirable, as they insure a careful consideration of the needs of the situation and tend to produce a better-balanced ratio of expenditures over the territory as a whole. The following tabulation shows the schedules used in preparing budgets for Division 4. Patrol costs are figured by an actual itemized patrol layout, as shown in Fig. 178. Material and oiling estimates are based on careful field inspection of the conditions on each road modified by previous experience with increases due to winter wear. Equipment is carefully checked up and estimates of additions made. Salaries for supervision and office force can be closely approximated from past records. The total of these schedules becomes the budget estimate. These estimates are prepared for each county. The schedules are interchangeable in amounts as far as expenditure goes within the county, which gives the necessary flexibility, but funds allotted to one county cannot be transferred to any other county. This restriction gives the necessary stability. At one time an effort was made to hold strictly to expenditures for each schedule, such as patrol, materials, equipment, etc., but this was found to be impracticable and the present system was adopted.

'ABLE OF MAINTENANCE FUNDS—DIVISION 4. TABLE SHOW-
NG EXPENDITURES AND PERCENTAGE OF SAME TO TOTAL EXPENDI-
TURES, EXCLUDING C AND E FUNDS

'xpenditures include schedule appropriations, 10 per cent funds, eneral funds, and maintenance taxes. Federal aid funds excluded. Expenditures are for calendar year

	1920 (780 miles)*		1921 (840 miles)	
	Expenditures	Decimal part	Expenditures	Decimal part
ch. A—Salaries	$ 40,573.05	0.1050	$ 49,059.32	0.1041
ch. B—Office supplies	756.89	0.0020	657.19	0.0014
ch. B—Livery	5,007.70	0.0130	5,613.31	0.0119
ch. B—Travel	3,058.43	0.0079	2,756.52	0.0059
ch. B—Communication	247.69	0.0006	247.06	0.0005
ch. B—Office rent	125.00	0.0003	1,000.00	0.0021
ch. B.—Advertising, printing	190.35	0.0005		
ch. B—Purchase trucks, mixers, and other large equipment	1,624.74	0.0042	11,061.96	0.0235
ch. B—Purchase war materials				
ch. B—Purchase tools	6,011.62	0.0155	8,240.33	0.0175
ch. B—Repairs to equipment	8,323.09	0.0215	11,890.84	0.0252
ch. B—Insurance for equipment	3,480.18	0.0090	700.08	0.0015
ch. B—Storehouse construction	6,416.01	0.0166	3,628.21	0.0077
ch. B—Storage rental	1,955.12	0.0051	1,967.44	0.0042
ch.				
ch. C—Resurface	6,384.29	......	44,168.08	
ch. D—Surface treatment	62,078.16	0.1606	116,420.25	0.2470
ch. E—Reconstruction	481,013.03	......	358,530.44	
ch. F—Foreman, labor, trucks, etc.	129,914.73	0.3361	155,883.86	0.3307
ch. F—Rental equipment	1,007.50	0.0026	870.75	0.0018
ch. F—Supplies for equipment	9,937.74	0.0257	8,284.47	0.0176
ch. F—Materials	105,856.60	0.2738	93,046.04	0.1974
ch. F—Drainage rights				
'otal—excluding C and E funds	$386,564.53	1.0000	$471,327.63	1.0000
'otal—including C and E funds	$873,961.85	......	$874,026.15	

Decimal part $= \frac{\text{Schedule expenditure}}{\text{Total expenditure minus C and E}}$. To calculate proposed hedule appropriations for ensuing year multiply (total appropriation inus C and E) by average or proposed decimal part.

* NOTE.—For % of mileage of different types see Table 110, page 582.

Appropriations	1920	1921
:hedule appropriations (budget)	$755,000.00	$735,520.00
) per cent funds—(used)	64,289.62	85,926.11
eneral funds—(interest, etc.)	14,682.54	16,892.69
'aintenance taxes—towns	33,950.00	34,600.00
'aintenance taxes—villages	8,318.50	8,479.35

TABLE 106.—NEW YORK STATE MAINTENANCE COSTS (1921

Type of pavement	Miles maintained		Cost per mile		
	Including change to more durable type	Including change to more durable type	Excluding change to more durable type	Excluding change to more durable type	Pavement only, excluding change to more durable type
Bituminous macadam, penetration method, macadam base, asphalt binder	3201.87	3186.82	$1033	$ 770	$ 581
Tar binder	255.06	255.03	543	540	341
Concrete base, asphalt binder	45.21	45.21	560	560	446
Tar binder	16.81	16.81	363	363	250
Water-bound macadam	2599.04	2536.29	2007	951	813
First-class concrete, 1:2:4 mix or richer	730.45	730.45	225	225	81
Second-class concrete, 1:2½:5 mix or leaner	187.65	181.50	1957	874	710
Hassam concrete	49.03	49.03	679	679	395
Brick pavement	280.45	280.19	352	307	226
Gravel	141.14	136.30	1861	890	767
Bituminous macadam:					
Mixed method, Topeka concrete base	65.42	65.01	831	299	128
Topeka, macadam base	29.72	29.72	769	769	354
Amiesite, concrete base	6.25	6.25	440	440	215
Amiesite, macadam base	4.88	4.88	53	53	10
Open mixed, concrete base	17.09	17.09	413	413	166
Open mixed, macadam base	15.43	14.68	3869	462	288
Bitulithic, concrete base	15.12	15.12	244	244	231
Warrenite-bitulithic	1.81	1.81			
Willite, concrete base	1.66	1.66			
Bitoslag, concrete base	2.31	2.31	37	37	
Sheet asphalt, concrete base	0.61	0.61	229	229	229
Gravel mixed, gravel base	8.38	7.72	5154	1978	1757
Henderson, macadam base	0.51	0.51			
Block pavements:					
Asphalt, concrete base	18.34	18.34	347	347	214
Asphalt, macadam base	1.73	1.73	1271	1271	1082
Wood	0.26	0.26			
Stone	3.58	3.58	9	9	
Brick cubes, macadam base	0.32	0.32	104	104	104
Bituminous subbase	15.70	15.70	332	332	266
Bituminous macadam, three-layer method	7.29	7.29	734	734	448
Kentucky rock, asphalt	17.55	17.55	686	686	614
Rocmac	0.15	0.15			
Three-strip dual	6.81	6.81	134	134	120
Two-strip dual	33.99	31.69	1 562	332	146
Total	7781.62	7688.42			
Average cost per mile	....	....	$1280	$ 744	$ 582

[A]verage Annual Maintenance Cost per Mile of Principal Types for the Past 7 Years, Excluding Change of Type

	1915	1916	1917	1918	1919	1920	1921	Average
Bituminous macadam, penetration method, asphalt and tar	$ 510	$ 483	$ 408	$ 557	$501	$590	$753	$543
Topeka on concrete base	......	205	245	435	144	335	299	277
Topeka on macadam base	......	256	393	1056	443	985	769	650
Water-bound macadam	1055	906	970	739	694	797	951	873
Brick	190	176	222	251	247	242	307	234
First-class concrete	129	141	112	160	214	227	225	173
Second-class concrete	1050	1080	1127	791	761	868	874	936
Gravel	955	587	918	909	771	704	890	819
Average all types	$ 750	$ 651	$ 643	$ 608	$560	$631	$744	

[T]able 106*A*.—Supplementary Extensions and Author's Comments

New York maintenance costs

Type of pavement	Reported 7 year average per mile	Supplementary comments[2]				
		Approximate cost pavement only		Relation[1] of reported cost to normal cost under proper conditions	Recommended allowance	
		Per mile	Per square yard		Normal condition	Unusually favorable
Penetration bituminous macadam	$543	$400	$0.043	High	0.035	0.025
Topeka on concrete base	277	150	0.016	Normal minus	0.020	0.015
Topeka on macadam base	650	500	0.053	High	0.025	0.020
Water-bound macadam	873	720	0.077	High	0.070	0.060
Brick	234	100	0.011	Normal	0.015	0.010
Cement concrete (1:2:4 or better)	173	50	0.006	Very low	0.015	0.010
Cement concrete (1:2½:5 mix)	936	800	0.085	Normal	Poor	type
Gravel	819	680	0.073	High	0.060	0.030

[1] Considers age, traffic and adequate design strength.
[2] Assuming pavement is used under proper volume of traffic (see page 6).

TABLE 107.—SUMMARY OF MAINTENANCE EXPENDITURES DEC. 1, 1921, to NOV. 30, 1922, STATE OF MASSACHUSETTS

Expenditures by types					
Type	Cost	Miles	Average cost per mile	Square yards	Average cost per square yard
Granite block	$ 53.80	1.114	$ 48.294	20,204	$0.0026
Cement concrete	11,789.40	96.458	122.223	1,044,399	0.0113
Bituminous concrete (asphalt)	19,469.50	163.526	119.060	1,771,329	0.0110
Bituminous concrete (tar)	1,251.74	3.528	354.801	37,826	0.0331
Bituminous macadam (asphalt)	55,603.29	252.677	220.056	2,699,764	0.0206
Bituminous macadam (tar)	109,656.39	255.737	428.786	2,735,921	0.0401
Bituminous macadam (hot oil)	34,041.54	40.330	844.075	354,001	0.0961
Water-bound macadam	318,689.60	417.269	763.751	3,989,280	0.0799
Gravel	107,686.72	152.748	704.930	1,407,036	0.0765
Dirt road	22,641.50	12.760	1,774.412	137,052	0.1652
Brick	74.39	0.134	555.149	1,987	0.0374
Sand and clay (layer)	2,425.81	2.670	908.543	25,067	0.0968
Wood block	0.00	0.054	0.000	568	0.0000
Totals	$683,383.68	1,399.005	$ 488.478	14,224,434	$0.0480

Comparison modern and old types			
	Modern types	Old types	Totals
Length (miles)	773,228	625,777	1,399,005
Area (square yards)	8,311,199	5,912,436	14,224,435
Per cent of area	58.4	41.5	100
Cost	$197,898.51	$485,485.17	$683,383.68
Per cent of cost	29.0	71.0	100
Cost per square yard	$0.0238	$0.0821	

Value of Smooth-riding Quality of Pavements.—A smooth easy-riding pavement is desirable on the score of personal riding comfort, reduced cost of motor operation (gasoline, tires, and jar damage), and reduced stress on the pavement due to impact of heavy trucks. Surface irregularities will vary with the type of pavement, care of construction, age of pavement, and perfection of maintenance, and they gradually increase as the pavements age until reconstruction becomes necessary.

Probably the most satisfactory method of measuring such irregularities at present (1923) is by means of the Vialog invented by Harley Dunbar of the New York State Department of Highways and manufactured by the Good Roads Machinery Co. of Kingston. This machine can be attached to an automobile. It records automatically in graphic form, as shown in the chart on page 548, the surface irregularities of the road. The machine is calibrated for the auto being used and the speed at which it is driven by means of careful test runs over a pavement of known irregularity. A duplicate record is made and the results agree remarkably well. The results can be examined for individual bumps or hollows or the average condition of the surface expressed as inches of irregularity per mile of road. This coefficient is reliable as a measure of relative roughness and of some value as a measure of absolute roughness. By means of records of this kind it is possible to set a reasonable limit of irregularity for acceptance of pavements of different types. It is also useful in keeping yearly records of the general condition of a state system and checks up the effectiveness of the maintenance and renewal programs. Being a mechanical device, it eliminates personal opinion and is a very useful instrument in highway work. The results of investigations of 2000 miles of New York State highways in 1923 can be summed up roughly as follows:

From the standpoint of riding comfort a pavement does not become disagreeably rough until the coefficient of roughness exceeds about 250″ per mile. The report on the 2000 miles investigated covers pavements of brick, asphaltic concretes, cement concrete, penetration bituminous macadam and water-bound macadam oiled. There is a wide range in roughness for each type, depending on age, maintenance, etc. All these types can be constructed originally and maintained for a considerable time in a comfortable condition for traffic. They all, in time, become rough and require resurfacing on the score of comfort and motor operating costs. The Vialog records verify the fact that the higher-priced pavements, such as asphaltic concretes, cement concrete, and brick, have a lower average roughness than the macadam type for the first few years, after which it becomes a matter of maintenance or reconstruction as to which has the advantage (see p. 546).

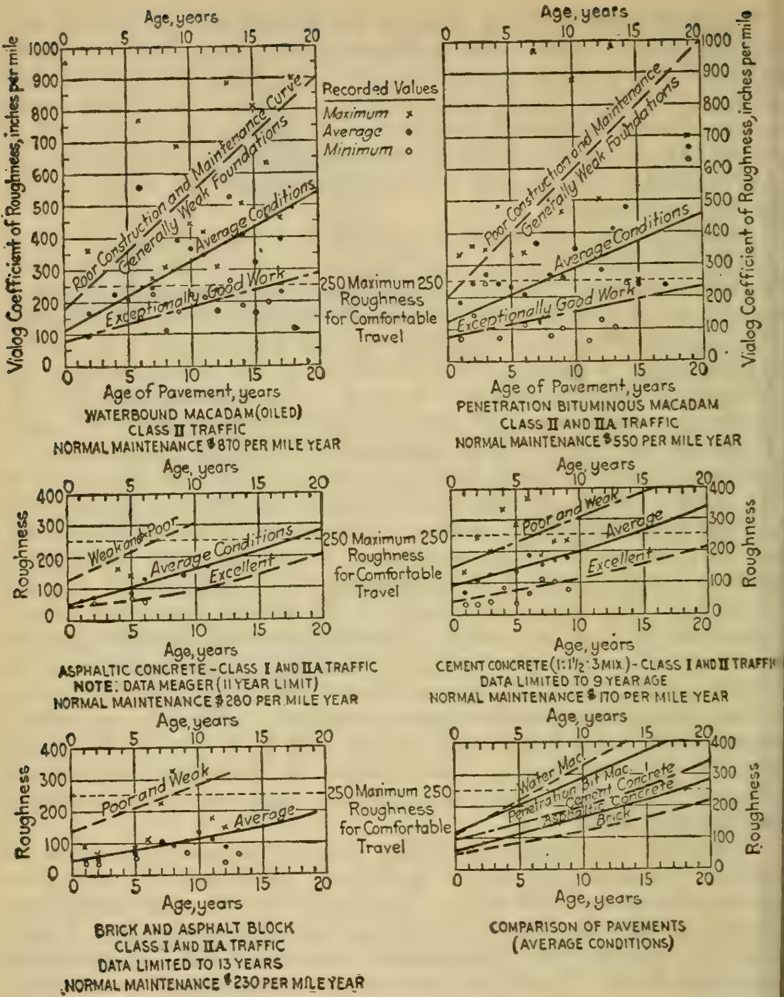


FIG. 175.—Graphs showing wide range and average value of Vialog coefficient of roughness for different pavements at differen ages. (New York State 1923.)

Based on average maintenance, that is, no specially high maintenance has been used to hold the roughness to a specified maximum. Reconstruction is resorted to when normal maintenance becomes ineffective.

NOTE: These graphs show the wide range in results obtaine under Public Works Programs and show conclusively the distin advantage of good Engineering Control. Any type of paveme well designed, constructed and maintained will give satisfacto results as far as traffic operation cost is concerned.

To anyone personally familiar with this district these recor have a human as well as a scientific interest. It is possible trace the gradual loss or gain in interest in the success of the vario types depending on the sympathies of the different administr tions and they also show the effect of knowledge and experien of the inspectors with different types.

Mr. Dunbar gives some tentative values subject to future change as follows. He recommends a maximum value of 50″ for

Type of pavement	New pavements, good condition		Old pavements, poor condition
	Range, inches per mile	Average, inches per mile	Range, inches per mile
Cement concrete	25– 80	65	250– 600[a]
Brick	20– 80	65	250– 300
Asphaltic concrete	35– 90	75	250– 300
Penetration bituminous macadam	80–150	100	250– 800
Water-bound macadam (oiled)	90–170	110	250– 1000

[a] Low-grade 1 : 2½ : 5 concrete.

acceptance of newly constructed concrete, brick, or asphaltic con cretes and a maximum value of 100″ for new bituminous macadam. The average roughness of roads at present under reconstruction runs from 500 to 700″ per mile.

EFFECT OF ROUGHNESS ON MOTOR OPERATION COSTS

Roughness increases the gasoline consumption of motors and he tire and engine wear. Any attempt to figure this closely is a iseless proceeding, but the general fact must be borne in mind in arriving at any reasonable conclusion as to the economic value of pavements and the necessity for effective maintenance. In time, Vialog records will be coordinated with gasoline consumption. No experiments along this line have yet been made. The following igures based on the present meager Vialog records must be conidered as speculative as far as actual cost of operation is concerned. However, they check the gasoline consumption tests, and serve to llustrate the value of smoothness.

Mr. Dunbar states that on a road having a coefficient of about o″, his chart distance measured by wheel revolutions was exactly qual to the actual lengths of the roads. Where the coefficients eached 500 to 700″, the chart distance by wheel revolutions xceeded the actual survey measured length of the road by from oo to 200′ per mile. That is, roughness actually increases wheel evolution due to jump, free spin, and extra length, exactly how nuch is not known. A conservative assumption is 0.5% per 100″ ncrease in Vialog coefficient.

Roughness virtually increases the rate of grade of the road. A onservative figure is 0.2% per 100″ increase in Vialog coefficient.

Considering gasoline consumption alone and using the values iven on page 98 of the first book of this series, "Highway Locaon," for distance and grade an increase in cost of motor operation

of about 8% can be derived.[1] This amounts to about $100 per mile per year for 100 average vehicles daily (36,500 yearly) for each 100″ increase in Vialog coefficient. Making the same assumptions discussed in Highway Location in regard to the actual value of gasoline saving, considering pleasure traffic and snow and ice during a portion of the year, this is reduced to $50 per mile per year per 100

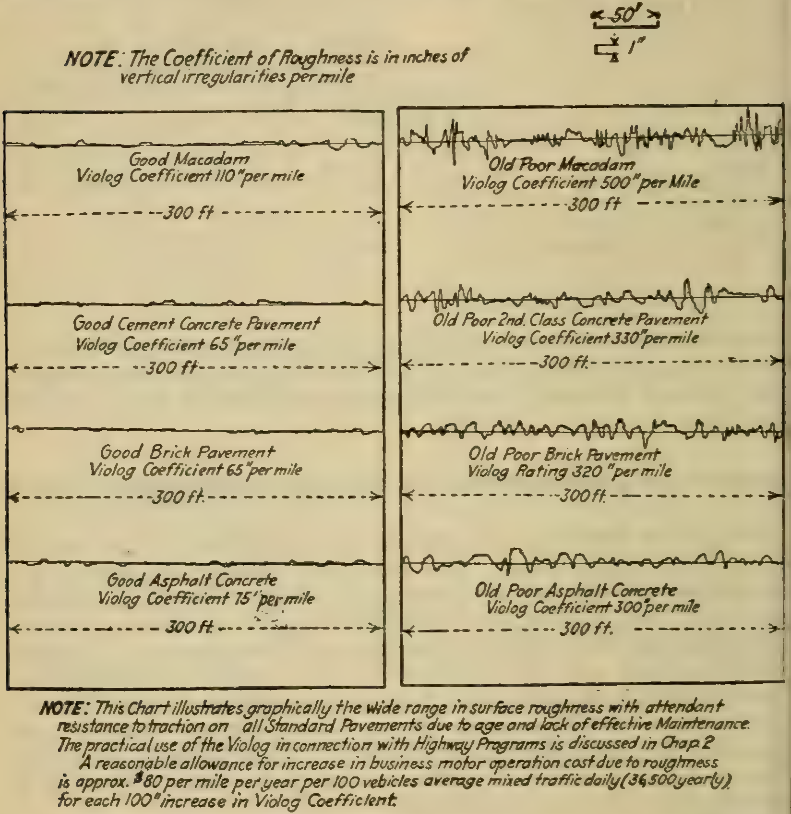


FIG. 176.—Vialog records of surface roughness (showing effect c age).

vehicles daily. For different volumes of traffic this is expresse in tabular form (p. 549) assuming a Vialog coefficient of 50″ pe mile as perfection.

In a similar way an approximation can be derived for tire wea: Any actual cost value for tire wear due to minor differences c roughness is a very illusive quantity. Recent investigations hav established that the difference in tire wear over gravel roads wit loose small pebble surface as compared with a smooth new rigi

[1] Allowing for an average difference in Vialog coefficient of roughness c 50″ per mile between average macadam and average Class *A* surfaces, th difference in gas consumption is 4%. Actual experiment gives a value of 5%

pavement may amount to as much as 1 ct. per vehicle mile. The actual difference in tire wear for ordinary road conditions, considering ice and snow in winter for any well-maintained gravel or macadam road with a bituminous surface carpet as compared with well-maintained rigid-base pavements, cannot amount to much. Assume some speculative figures merely to bring out the fact that there is some difference in cost of this phase of road travel over different types.

Ordinary tire wear on improved roads is assumed at 1.5 ct. per average vehicle mile for roughness of, say, 200″ Vialog rating. A well-maintained and renewed road system should not range more than 50 to 300″ per mile. The increase in wheel travel distance as

Volume of total traffic, vehicles per day	Vialog coefficient, inches per mile					
	50	100	200	300	400	500
	Values below are estimated yearly saving in business consumption of gasoline					
100	$0	$ 25	$ 75	$ 125	$ 175	$ 225
200	0	50	150	250	350	450
300	0	75	225	375	525	675
400	0	100	300	500	700	900
500	0	125	375	625	875	1,125
1,000	0	250	750	1,250	1,750	2,250
1,500	0	375	1,125	1,875	2,625	3,375
2,000	0	500	1,500	2,500	3,500	4,500
3,000	0	750	2,250	3,750	5,250	6,750
4,000	0	1,000	3,000	5,000	7,000	9,000
5,000	0	1,250	3,750	6,250	8,750	11,250
10,000	0	2,500	7,500	12,500	17,500	22,500

between 50 to 500″ rating amounts to about 2%. The added jar damage above 250″ rating probably does considerable more damage. Assume the same rate of tire cost as for gasoline previously derived, 8% per 100″ Vialog increase. This amounts to approximately $50 per mile per year for 100 average vehicles daily. Combining this value with the gasoline saving Table 108 is derived.

This table indicates in a general way the importance of keeping a system in fairly smooth-riding condition. To illustrate with the New York system, Division 4. The coefficient of roughness of most roads when actually reconstructed is about 500 to 700. This gives an average coefficient for the life of the pavement of about 300 to 400. The average volume of traffic for this territory is about 800 to 1000 vehicles per day (Class II traffic); that is, the cost of motor operation due to the degree of perfection actually attained probably is increased about $2000 per mile per year over a system in perfect condition. As later discussed, it is probably impracticable to attempt to maintain and renew a system with a maximum allowable roughness before renewal of under 250″ Vialog rating. If the system were maintained on this basis, the average coefficient would be about 150 to 200, which might result in a yearly saving in motor operation of about $800 per mile ($2000 minus $1200).

Table 108.—Table of Possible Difference in Motor Operation Cost per Mile Year for Different Volumes of Traffic and Different Degrees of Surface Roughness (1923 Cost Conditions)

(Based on gas consumption and tire wear)

Volume of traffic, vehicles per day	Vialog coefficient, inches per mile					
	50[a]	100	200	300	400	500
100	$0	$ 40	$ 120	$ 200	$ 280	$ 360
500	0	200	600	1,000	1,400	1,800
1,000	0	400	1,200	2,000	2,800	3,600
1,500	0	600	1,800	3,000	4,200	5,400
2,000	0	800	2,400	4,000	5,600	7,200
3,000	0	1,200	3,600	6,000	8,400	10,800
4,000	0	1,600	4,800	8,000	11,200	14,400
5,000	0	2,000	6,000	10,000	14,000	18,000
10,000	0	4,000	12,000	20,000	28,000	36,000

[a] Vialog rating of 50″ considered as practical perfection.

It is a well-recognized fact that funds have been insufficient and that the roads are too rough in their last stages before reconstruction. The average actual expenditure for maintenance and renewal has been about $1100 per mile for the last few years. The discussion of maintenance cost on page 524 indicates that approximately $1500 to $2000 per mile per year is necessary for this territory; the above data indicate that this increase is probably justified from the standpoint of economic motor operation as well as for the more obvious reason of comfort in riding.

Difference in Operation Cost on Different Surfaces.—A rough approximation can now be derived on the assumption that roads will be maintained and renewed on the basis of a maximum coefficient of roughness of 250″ Vialog rating.

Class B.—The macadam type of surface has an initial rating of 100″ and a final rating of 250″, or an average of 175″.

Class A.—The asphaltic concretes, cement concrete, and brick range from 50 to 250″, average 150″, giving an average difference between Classes *A* and *B* for total life of pavement of about 25 to 50″ Vialog rating. Expressed in money value as yearly cost and capitalized cost for different volumes of traffic, Table 109 is constructed.

In computing the total yearly cost of a pavement to the community it is just as well to give some weight to this item (see Official Reports, pp. 69 and 771).

For average conditions in Division 4, western New York, considering construction, maintenance, renewal, interest on construction, and difference in motor operation cost, the general conclusion to be drawn is that the macadam type of surface usually becomes uneconomical at a volume of traffic of between 1500 to 2000 vehicles daily. At this point an old macadam road can be resurfaced with asphaltic concrete and brought up to the operation efficiency of Class *A* pavements.

TABLE 109.—TABLE OF INCREASED COST OF OPERATION ON MACADAM TYPE OF SURFACE (CLASS *B*) COMPARED WITH CLASS *A* SURFACES (1923 COST CONDITIONS)

Volume of daily traffic	Increased yearly cost of operation		Capitalized value of increased cost at 5%	
	Per mile	Per square yard 18′ road	Per mile	Per square yard 18′ road
100	$ 20	....	$ 400	
500	100	0.01	2,000	$0.20
1,000	200	0.02	4,000	0.40
2,000	400	0.04	8,000	0.80
3,000	600	0.06	12,000	1.20
4,000	800	0.08	16,000	1.60
5,000	1,000	0.10	20,000	2.00

The student is again cautioned not to overemphasize the importance of hair-splitting economic value figures. They are included to illustrate general principles, and the values and conclusions given throughout this text have been adjusted to agree with actual observed road conditions.

Effect of Smoothness on Impact.—Table 67 (p. 372), gave a rough summary of the U. S. Office of Roads investigation on impact for known surface irregularities. Impact increases rapidly with the roughness and becomes a very destructive element unless the pavements are kept moderately smooth by effective maintenance. The section on Design (p. 373), assumed impact allowances based on ¼ to ½″ irregularities. An examination of the Vialog records show that such irregularities are quite common and continuous on the macadam type for an average coefficient of 120 to 200 per mile and occur at joints and cracks quite frequently on the rigid type of pavement with coefficients as low as 65 to 100 per mile. Where the coefficient rises to 300 to 500 per mile surface irregularities of 1 to 2″ are quite common and the pavement becomes not only uncomfortable and expensive to operate over but also is stressed beyond the design loading.

TENTATIVE MAXIMUM ALLOWABLE VIALOG RATING

From the standpoint of comfort, cheapness of operation, and cost of construction due to impact stresses it seems desirable to place a maximum limit of roughness at about 200 to 250 Vialog rating. As a road ages, the cost of maintenance will increase to retain this value and when the maintenance cost exceeds the proper limit for each type reconstruction or resurfacing must be resorted to. It is believed that if rural pavements are designed according to the principles outlined in Chapter VI, that the maintenance costs and average life before renewal become practical necessities, either on the score of economy or appearance or travel comfort will corre-

spond closely with the figures given in Tables 97 and 105 pages 520 and 536.

An examination of the Vialog records in conjunction with ordinary New York State maintenance costs and procedure indicates that it is impracticable to attempt to reduce the maximum coefficient of allowable roughness below 200 to 250, as it would increase maintenance and renewal costs out of all proportion to the benefits derived.

A rough approximation of the maximum economic limit of maintenance cost per year for the different types is given below. When this limit is exceeded, resurfacing or reconstruction is desirable from the standpoint of paving cost.

Type of pavement	Class I traffic		Class II traffic		Class III traffic	
	Per square yard	Per mile	Per square yard	Per mile	Per square yard	Per mile
Asphaltic concretes	$0.17	$1700	$0.14	$1200		
Brick[a]	0.17	1700	0.14	1200		
Cement concrete[a]	0.17	1700	0.14	1200		
Bituminous macadam	0.17[a]	1700	0.15	1300	$0.12	$1000
Water-bound macadam (oiled)	....	.....	0.18	1600	0.13	1100

[a] Resurfaced with bituminous concrete.

As a matter of fact, maintenance costs rarely reach these maximums before renewal is resorted to, as the trouble and inconvenience to traffic from excessive maintenance work are the deciding factors rather than low total cost of maintenance and renewal. In Division 4, when it is necessary to spend about $1000 per mile to keep a road in fairly good shape, reconstruction is resorted to on the score of practical expediency.

The value of smoothness and the economic limit of maintenance expenditure before renewal is resorted to completes the discussion of maintenance economics.

MAINTENANCE METHODS

Methods will be treated in two parts: first, high-type, hard-surfaced pavement, and, second, low-type earth, sand-clay and gravel roads.

MAINTENANCE OF HARD-SURFACED PAVEMENTS

Organization.—A typical organization scheme for high-class state-improved systems with extensive mileage is shown in Fig. 177. For a system of this character (Division 4), the work can be effectively handled by a combination of patrol, gang work, and contract awards. The success of the program requires good judgment in

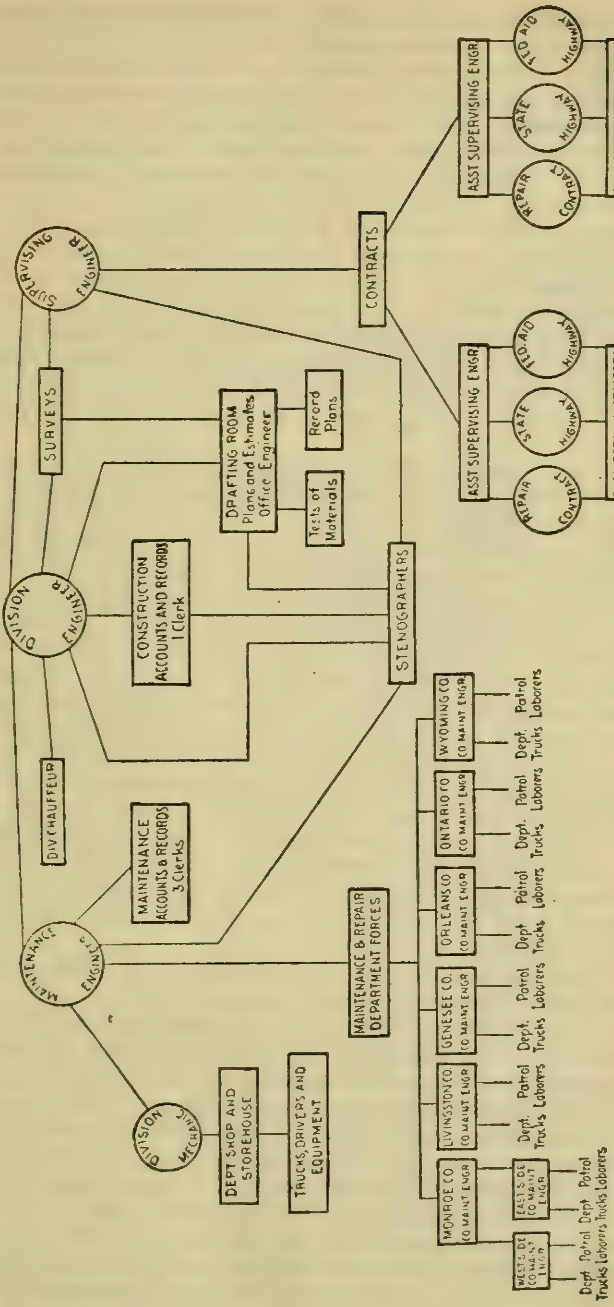


FIG. 177.—Organization chart, Div. No. 4, Western N. Y. 1000 miles state road under maintenance.

a well-balanced utilization of these different methods supplemented by correct use of materials and equipment.

a. One-man Patrol with Horse Rig.—This organization unit is very limited in usefulness for a high-grade compact system of heavy-traffic roads. It is useful for isolated roads under light traffic. The usual length of patrol is from 3 to 7 miles (see Figs. 178 and 179). The usual price paid for patrolman, including horse and rig, is about $4.50 per day (1922) for about 200 days per year. In Division 4, which is used for illustrative purposes, only 40 out of 860 miles were maintained by horse patrol in 1922. Patrol of this kind handles minor surface repairs of pavements.

On macadam roads the equipment used is as follows: one-half-cubic-yard wagon, pick, mattocks, shovel, broom, tamper, rake, asphalt bucket, scythe, straightedge, special equipment furnished from division storehouse for scrapping shoulders, or any special jobs; stone, bitumen, etc. delivered in stock piles by special truck gang.

On rigid pavements, a hook to clean out cracks and necessary chisels, bars, sledges, etc. for removing and replacing portions of the pavements are provided.

b. Small 1-ton Truck Patrol (One to Four Men).—This organization is a very useful and popular unit for maintenance work. It is flexible, speedy, and economical. The usual length of patrol ranges from 15 to 25 miles (see Figs. 178 and 179). The usual price paid for patrolman, including truck, is about $7.50 per day (1922). The usual price for extra helpers is from 35 to 50 cts. per hour. These patrols work about 200 days a year in northern climates. They take care of minor surface repair of pavements and keep shoulders, ditches, guard rail, culverts etc. in shape. On Division 4 this type of patrol takes care of 530 miles out of the total of 860 miles. On macadam roads, the equipment consists of 1-ton truck, shovels, picks, mattocks, push brooms, rakes, tampers, asphalt pouring pots, ax, scythes, straightedge. These small tools are supplemented from the general division equipment by a small asphalt-heating kettle, and one-bag batch concrete mixer for cold patch work as required.

Where patrols of this kind work entirely on rigid-pavement roads, the force of men is generally reduced to two.

c. Three-ton Truck and Gang of Six to Twelve Men.—This organization unit is a recent development and serves very efficiently for work on roads requiring a large amount of surface patching, small areas of complete reconstruction, or extensive surface oiling. Gangs of this nature do all work not sufficiently important to warrant formal contract awards. They are, as a rule, responsible for the direct maintenance work on from 17 to 40 miles of road (see Figs. 178 and 179) and in addition deliver materials, reconstruct weak areas, and handle surface oiling. In Division 4 (used as illustration) 16 gangs of this nature handled the maintenance on 300 miles and in addition they reconstructed in 1922 approximately 4.3 miles of road and handled all the surface-oiling treatment on the division.

The equipment required other than the small tools previously listed for patrol is roller, oil distributor, scrapers, tractors, any special machinery desired (division equipment list, p. 556).

d. Contract Work.—Extensive reconstruction and oiling are usually handled by contract awards, but oiling is gradually being taken over by these gangs, as they do better work, cheaper than the contract method.

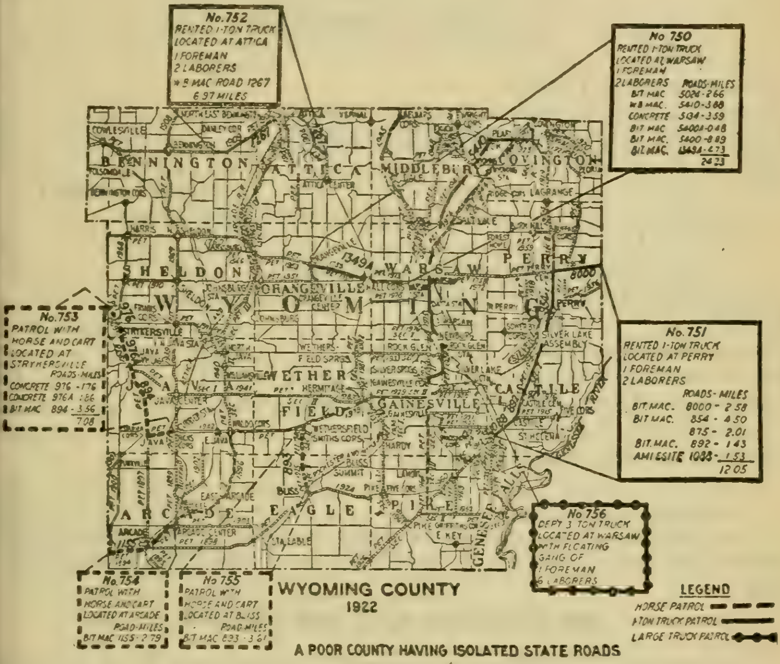


FIG. 178.—Maintenance patrol layout.

Large Equipment.—The number and kind of large machinery required will vary for each district. The following list, Division 4, gives an idea of the units found useful for a territory of this general character as described on page 523. A storehouse with repair and overhauling equipment is necessary.

Storehouse Organization (Division 4).—A workshop equipped with traveling hoists, electric drills, grinders, lathes, milling machine, drill presses, and small tools to enable mechanics properly to take down, overhaul, repair, and reassemble trucks and other equipment. Floor space of workshop should be large enough to place six or eight trucks at a time on the floor, say 40 by 80 or 50 by 100′.

In addition, there should be shed room enough to house all trucks during winter and equipment brought in for storage or overhauling, also a stockroom for small tools.

Mechanics at Storehouse.—One foreman mechanic is in charge of storehouse and all equipment, whether at storehouse or working on roads. He should have a small truck in order to make inspec-

tion and repairs to plant in field; also a helper to be at storehouse at all times. In winter months, in order to overhaul trucks and plant properly, there should be, in addition, at storehouse seven or eight mechanics. These latter could be the best among the truck drivers used in the summer on the road work.

LARGE MACHINERY EQUIPMENT (DIVISION 4)

(900 miles of state road)

10-ton rollers	7
5-ton caterpillar tractors	1
Steam scarifiers to attach to 10-ton rollers	2
Large blade scrapers (Austin Rip Snorter)	1
4000-lb. 10′ blade scraper	7
3-ton trucks, supplemented by a few additional rented trucks, 3 equipped with 800-gal, cold-oil distributors	2c
¾-ton speed trucks	4
1-ton Ford trucks rented with patrolman	3c
Asphalt distributors for penetration work with roller	3
Portable belt-conveyor unloaders	7
Street sweepers (rotary, horse drawn)	7
Small one-bag batch concrete mixers (cold patch)	15
Small concrete paving mixers (three-bag batch)	2
Necessary side forms and small tools	
Portable asphalt-heating kettles:	
300 gal	1c
150 gal	12

For this division, quarrying and crushing equipment is not needed, as commercial stone can be obtained readily at a reasonable rate.

MATERIALS AND METHODS

The general principle of pavement maintenance is to prevent noticeable wear rather than to neglect minor flaws and then repair serious damage. Patch any hole large or small as soon as it appears. "Catch them young and treat them rough." Effective maintenance increases the life of pavements, increases traffic comfort, and reduces the cost of traffic operation. It is the best possible investment for the community and is essential to the success of any highway program. Maintenance includes the upkeep of ditches, shoulders, culverts, guard rails, guide signs, and pavement repair; the fundamental principle of pavement work is to repair like with like; that is, a hole in an earth road should be repaired with earth, gravel with gravel, macadam with macadam, Amiesite with Amiesite, Topeka with Topeka, brick with brick, etc. This seems perfectly obvious, but it is violated with clockwork regularity and the result is a patch that looks badly, wears badly, rides badly, and costs like the devil; it is a great temptation to use an easily manipulated patching material as a cure-all like David Harum's cure for spavin, ring-bone, pips in hens, etc., but it is poor policy. The following discussion outlines briefly the materials and methods in ordinary well-balanced practice.

Incidental Maintenance.—Shoulder maintenance consists in cutting weeds and grass either with farm mower or hand tools, maintaining the elevation and shape of the earth by means of blade scrapers hauled with trucks, roller or tractor (see Fig. 179), drags or hand-tool methods, or the addition of stone, gravel, etc. bound with bitumen on the main-traveled roads. The cost of this work has a wide range, depending on the excellence of the maintenance and on the width of pavement, and volume of traffic; for pavements having the widths recommended (p. 6), and where the maintenance is fairly effective, a fair set of costs is about as follows:

	Per year
Class I traffic (18′ pavements)..............	\$200–\$400 per mile
Class II and Class III traffic (16′ pavements)	\$100–\$200 per mile
Class IV traffic (12′ pavements)............	\$100 per mile

Ditch cleaning is largely a hand-tool proposition supplemented in some cases by blade-scraper work.

Guard rail, signs, etc. are routine mechanical operations.

This incidental work is about the same for all types of pavement.

Macadam Pavements.—Macadam-pavement maintenance involves repair of small areas of structural weakness, such as frost boils, etc., the repair of potholes in the surface, due to raveling of the top course, and the care of minor surface irregularities and roughness due to traffic wear.

Frost Boils.—Weak areas are dug up and replaced by new pavement of adequate depth reinforced by underdrains if necessary; this work follows the principle of depth design and construction methods described under Macadam Design and Construction (pp. 366 to 449). For a well-designed pavement, this kind of work rarely exceeds over 3/10 of 1% of the area per year. In 1917 in New York State 82 out of a total of 5600 miles broke through, or 1½% of the area. These breaks occurred largely on the old, thin roads, totaling 2000 miles, or a percentage of 4.2 for these old, weak pavements. For well-designed macadam pavements the item of frost-boil repair should not exceed \$50 per mile per year. Work of this kind is done by the large gang organization unit previously described.

Repair of Potholes.—Potholes due to ravel of the surface and not to structural weakness are of two classes: incipient depressions less than ½″ deep, and well-defined holes.

The first class of surface defect is remedied by sweeping out the hole, painting it with a thin coat of maintenance bitumen (cold-patch fluid) by means of pouring pot and broom, adding dustless stone or slag screenings, and tamping thoroughly. Screenings containing sharp flint or other hard material should not be permitted on account of tire damage.

Well-defined holes are repaired by cutting out the edges of the hole to a square edge, painting the edge and bottom with cold-patch liquid, and filling the hole with a cold-patch mixture of bitumen, stone, and sand, or stone and screenings. For depressions of about 1″ depth, ¾″ stone is used. Holes deeper than 1″ are

dug out to the full depth of the top course, squared up and filled with regular-sized top stone (1½ to 2½″), rolled with a 10-ton roller. Some engineers advocate light rolling, but experience indicates that the stone should be hard rolled but not crushed. Hot-binder-grade bitumen is then poured as for penetration macadam and filled with screenings. The patch is rolled lightly at once and thoroughly the next morning after the bitumen has hardened a little. A seal coat can be added, but is rarely necessary, as patching of holes is generally preliminary to extensive surface oiling. Work of this kind is done by the regular patrol gang. The amount of material required has a wide range for different roads.

In 1922, patching holes of this kind on Division 4 required from 10 to 60 tons of stone or slag per mile (50% ¾″ and 50% screenings) and from 200 to 1200 gal. of some kind of bitumen per mile. Cost of this work is difficult to segregate, but is probably about $150 to $200 per mile average on water-bound and about $50 to $100 per mile on bituminous macadam under Class II and Class III traffic.

Cold-patch bituminous compounds are a comparatively recent development. There are a number of satisfactory materials on the market, the best known being some form of

1. Asphaltic emulsion.
2. Tar cut back.
3. Asphalt cut back.

Good results can be obtained with all these materials. Locally, the best results have been obtained with the asphaltic emulsion, but it is the most expensive and will not keep over winter. The tar cut back is better for early spring use as it flows better at cool temperatures and is not damaged by winter storage. The cut back cold-patch mixture requires from 15 to 20 gal. of standard fluid per cubic yard of mixed stone and sand, or stone and screenings. Asphalt emulsion requires a little more, about 0.9 gal. per cubic foot of stone. The manipulation of this material is well described in the following quotation from the Barrett Company's "Vest Pocket Handbook." Maintenance men say that the greatest difficulty they experience in connection with the use of this material is the tendency on the part of the patrolman to use too much fluid as the mixture is easier to prepare under such treatment. Don't use too much bitumen, as it produces a patch which tends to creep and shove under traffic action.

MANIPULATION OF TARVIA-KP

"Tarvia-KP is a material that can be used for patching at any time of the year. It is as serviceable in winter as it is in summer.

"Intelligent use keeps bituminous macadam and other bituminous pavements in perfect condition all the time. Holes in wood block, brick, and stone block may be successfully patched with it.

"Tarvia-KP is used cold. It is used at any time, in any place. A batch of the mix may be made today, and need not be used until it is required, weeks hence. Batches may be made on rainy days and stored away for use later on, thus keeping the repair gang busy, rain or shine.

Holes and How to Patch Them

"Usually holes are one of two kinds: They either are breaks in the skin surface of the road, or they are deep depressions. The breaks can usually be mended by carefully sweeping them out and proceeding as is described below under the Penetration Method; the deep depressions are repaired by either the mixed method or the penetration method.

Deep Depressions. Mixed Method

"No hard-and-fast rule for proportioning the ingredients of the mix can be given, as sands and stone vary greatly in quality; but, in general, the following will be found to work satisfactorily:

"One cubic yard of a mixture of 1 part sand and 3 parts $\frac{3}{4}''$ stone (stone held on $\frac{1}{2}''$ screen and passing $1\frac{1}{4}''$ screen), 16 to 18 gal. of Tarvia-KP.

"These may be mixed by hand, using shovels and turning the mix about seven times, or they may be mixed in a concrete mixer of the batch type. A full minute is required to mix the materials in a mixer.

"After the mix has been made, it may either be used immediately on the road or it may be stored away for future use, covering it over with a tarpaulin or other suitable shield to keep the rain out. While the mix is set away it is curing. A hard crust will form on the outside, but this will in no way injure the bulk. The mix will be found to be in perfect condition 6 weeks, and even longer, after mixing. A pickax will loosen the tarred stone so that it may be shoveled into a cart or wheelbarrow and taken to the point of application.

FILLING HOLES

"Cut the sides of the hole vertically, and clean out the old material thoroughly. If the hole is over an inch in depth, fill to within 1″ of the top with clean, broken stone, and tamp. The larger the stone up to $2\frac{1}{2}''$, that can be used for this work, the better. In other words, the stone is to furnish a firm foundation for the patch. The stone should be thoroughly rammed. Then paint the hole to be patched a light coat of Tarvia-KP (from $\frac{1}{4}$ to $\frac{1}{2}$ gal. to the square yard), and deposit the mix therein. Place a quantity sufficient to fill the hole a little more than flush with the surface, and then tamp with a heavy iron tamper, or roll with a road roller until the surface of the patch is level with the surrounding surface of the pavement. Apply a light, seal coat of Tarvia-KP, cover with screenings, and the patch is ready for traffic.

"A dish-shaped shallow hole may be patched the same way, or by the penetration method.

"Great care must be taken to see that not too much Tarvia-KP is used. Use too little rather than too much. Too much acts as a lubricant for a time and tends to make the patch creep out of the hole.

"It does not matter how large or how small the patch is, Tarvia-KP will mend it.

PENETRATION METHOD

"Instead of mixing the ingredients, a penetration-method patch may be made. Owing to the fluidity of Tarvia-KP the method is not usually so good as the mixed method except for very small holes. The hole is cleaned out, a paint coat of the liquid, about $\frac{1}{2}$ gal. to the square yard, is spread over the bottom, and 3″ stone is deposited so that the hole is slightly more than filled. Tarvia-KP is then poured over the stone, using for each square yard about $\frac{1}{2}$ gal. for each inch in depth of stone. The patch is covered with screenings and thoroughly tamped with a heavy iron tamper. A light seal coat about $\frac{1}{2}$ gal. per square yard is then spread over the patch and it is allowed several days in which to set up before traffic is admitted, although this is not absolutely necessary.

PATCHING SHEET ASPHALT[1]

"The old sheet asphalt and binder should be removed and the hole cleaned out. Paint the bottom of the hole with a light coat of Tarvia-*KP*. Place the mix, roll, spread the seal coat of Tarvia-KP, and use screenings as before. The mix should be made as follows:

[1] For temporary relief only.

"One part sand, three parts stone, varying in size and grading of stone to suit the hole to be patched and local stone conditions. The mix should be so proportioned that it will tamp solid. No excess sand should be used or a rolling patch will develop. Sixteen to eighteen gallons of Tarvia-KP to the cubic yard is the usual requirement.

MISCELLANEOUS PATCHING[1]

"**Concrete Pavements.**—Holes in brick and cement pavements may be patched in the manner already described. Cracks in these pavements may be repaired by first cleaning them out thoroughly, and then filling them with a mastic made of Tarvia-KP and fine sand, using a slight deficiency of sand so that the liquid may find entrance into the crack or joint, and yet not thin enough to flow away easily.

"**Wood-block Pavements.**—It sometimes happens that a hole develops in a wood-block pavement and that there are no blocks available to patch with. A Tarvia-KP patch, made the same as for bituminous macadam, will serve well until such time as a wood-block patch can be substituted.

BRIDGE FLOORS

"The wear and tear on plank floors on bridges is considerable and has led a number of county engineers and others to take up the planks and substitute a concrete floor. This is always a dangerous change to make, for the bridges are not usually designed for the increased dead load of a concrete floor. A safer and better plan is to put a Tarvia-KP top over the plank floor. This will add comparatively little weight and will provide an excellent roadway. The method of construction is as follows:

"Sweep the planks thoroughly and when they are dry apply a light paint coat of Tarvia-KP, about ¼ gal. to the square yard. Place a 2″ mixed top made of ¾″ stone, sand, and the liquid in the proportions given under "Holes and How to Patch Them." This may be placed to have a depth of 2½″ at the center and 1″ at the sides, when rolled. Roll or tamp well, give a ⅓-gal. seal coat of the liquid and cover with screenings or sand.

RESURFACING OLD MACADAM WITH TARVIA-KP MIX[2]

"Usually the old macadam is scarified and reshaped with the addition of new stone if necessary. If, however, the surface is in fairly good condition, the ruts and depressions are repaired with a mix of crushed stone and Tarvia-KP. The road is then swept and a paint coat of the liquid applied to the entire road surface. On this a mix of sand, broken stone, and Tarvia-KP is spread to a depth of 2½″ and rolled. When the rolling is completed, a seal coat of Tarvia-KP is applied and the new top is covered with pea gravel or stone chips. The road is allowed to set up for several days before traffic is turned onto it.

"The mix is made in a concrete mixer. For a small mixer a good proportion has been found to be 1 cu. ft. of sand, 4 cu. ft. of stone, and 3 gal. of Tarvia-KP. These are mixed for one full minute at least, and are then dumped in a pile to cure for a week. At the close of the day's work, a quart of kerosene and two shovelfuls of stone are revolved in the mixer to clean it out.

"If the mix shows a tendency to wave under the roller to any great extent, let it cure for a day or so. The volatile oils will evaporate, leaving the mix stiffer and firmer.

"Tarvia-KP is supplied in barrels. It can be stored without deterioration indefinitely, even in winter weather. It is well, however, to stir the contents before using. The barrels hold approximately 50 gal. Where there are facilities for storing the liquid in bulk, it may be supplied in tank cars. The storage tank should be supplied with coils or other means for heating the liquid in cold weather. Tank cars hold from 8000 to 10,000 gal. Tarvia-KP should never be heated in open tanks or kettles. It can never be mixed with very hot stone or sand.

"Use Tarvia-KP sparingly. You can always add, but you cannot subtract."

[1] For temporary relief only.
[2] Resurfacing with cold patch is rarely desirable.

Calcium Chloride Treatment.—Calcium chloride is often used as a temporary maintenance method for the first season on water-bound roads. About 1¼ lbs. per sq. yd. is applied by an agricultural drill for the first application and about 1 lb. per sq. yd. for succeeding applications. Two or three applications per season should keep a new Waterbound Road in good condition under Class III Traffic. The particular value of calcium chloride is to prevent ravelling the first season. Oiling is generally resorted to the second season after the road has been well compacted by traffic. For the cost of apply calcium chloride see page 1220.

Surface Oiling.—Surface oiling produces the final smooth, dustless surface demanded by modern traffic. It is the final stage of macadam maintenance. All structural defects and surface holes must be repaired before surface oiling is done. There are three well-defined conditions in connection with this work which require different methods of treatment.

1. Light oiling to liven up a comparatively smooth surface.
2. Medium treatment to smooth and seal a rough surface.
3. Heavy hot oiling with thick cover mat to repair temporarily a road in very poor condition.

The light type of treatment is used where the surface is smooth but requires some bitumen to liven up the binder on penetration bituminous macadams. For a treatment of this kind, 0.2 to 0.25 gal. of bitumen is applied after the road is swept clean of dust and loose material of all kinds. The oil is applied by mechanical distributors, one-half of the road being treated at a time to avoid inconvenience to traffic. The oil is immediately covered with a light coat of clean, sharp sand, dustless stone, or slag screenings, using about 18 to 30 tons of cover per mile of 16′ road. The road surface must be clean when the oil is applied but slight dampness does no harm so long as water is not standing in pools. Either a light cold tar or light asphaltic oil can be successfully used. Locally, the tar is preferred for treating water-bound macadam or tar-penetration macadams, and the light asphaltic oil is preferred for treating asphalt penetration macadam (see Specification, items B. and R.C.O., p. 1397 and 1396). Sharp sand makes the best cover material, as it is less likely to cause excessive tire wear.

The medium type of treatment is used where the surface is rough. The manipulation is the same as for the light treatment except that a little more oil is used, from 0.3 to 0.4 gal. per square yard, and more cover, 80 to 100 tons per mile of 16′ road; ¾″ stones rolled until they are completely crushed may be used for cover, but the dustless screening cover rolled in is better practice.

The heavy, hot-oil treatment is used sparingly, as when a road gets into the condition where this method is needed it is generally better policy to do a good job of resurfacing. This method is used as a stop gap to save a road where the funds are insufficient for a new top course. From 0.6 to 0.7 gal. per square yard of binder-grade bitumen (either tar or asphalt) is applied hot to the well-cleaned surface and covered with from 100 to 130 tons per mile (16′ road) of a mixture of about 75% ¾′ stone and 25% dustless screenings.

This cover is rolled hard until all the $\frac{3}{4}''$ stones are crushed down to the screening size. The cost of this treatment ranges from \$1200 to \$1600 per mile of 16′ road (1922 cost conditions).

Surface oiling of either the light or medium method is routine procedure in macadam maintenance. It starts the second season on water-bound roads and continues at irregular intervals throughout the life of the surface. It costs on the average about \$350 to \$450 per mile for each oiling, which amounts to about \$300 per mile per year average under Class II traffic for the water-bound type. On penetration-bituminous-macadam roads it starts the second season on tar penetration and the third or fourth season on asphalt penetration and continues at irregular intervals as required. It costs about \$350 to \$450 per mile for each oiling, which amounts to about \$150 to \$200 per mile per year average under Class II traffic. All costs are 1922 cost conditions.

The following tabulation gives a rough idea of the relation of the different items of maintenance to total yearly cost for 16′ macadam roads well designed and reasonably well maintained.

Class of work	Bituminous macadam, Class II traffic, cost per mile	Water-bound macadam, Class III traffic, cost per mile
Repair of weak areas	\$50	\$50
Surface patching	\$ 50–\$100	\$150–\$200
Surface oiling	150– 200	200– 300
Shoulders, ditches, etc.	150	100
Totals	\$400–\$500	\$500–\$650

NOTE.—Each of these items includes an allowance of 10% for administrative overhead and equipment.

The following quotation from the report of Fred Sarr, former Maintenance Deputy of New York State, reinforces the data given.

"Efficient maintenance of macadam pavements, particularly of the water-bound type, of which there are 2535 miles in the state system of improved highways, necessitates frequent surface treatments with bituminous material or constant patching of the holes that rapidly develop under the present-day motor-vehicle traffic.

"Frequent surface treatments are objectionable not only from a traffic standpoint, but from the fact that such treatments tend to build up an unstable mat of bituminous material and mineral aggregate on the surface of the pavement that is displaced by the fast-moving motor vehicle traffic and develops a rough and uneven surface.

"It has, accordingly, been the policy of this Bureau to restrict the use of surface treatments and wear the surface mat down, as this is possible before giving another general surface treatment.

"This method, while tending to provide a smoother surface, requires constant patching during the later stages of the wearing-down process.

"Much time and thought have been given to the study of the results obtained by various methods of manipulation and materials used in patching macadam surfaces.

"In making these patches to pavements carrying any considerable amount of motor-vehicle traffic, it is necessary to bind the mineral aggregate with some form of bituminous material.

"Light asphaltic oils and refined tar products, similar to those used for surface treatments, have been used extensively for light, thin patches, paint-

ing the area to be patched with the bituminous material and covering with stone chips or sand.

"Heavy binders that require heating have been used in the same manner.

"The most satisfactory results have been obtained, where the required patch must be ½″ or more in depth, by mixing the mineral aggregate with a heavy asphalt or tar binder, cut back with light voltaic oils to a consistency that will mix readily with the mineral aggregate when cold, also with an emulsified asphalt binder in the same manner.

"The bituminous material and stone aggregate, being mixed either by hand or in a small concrete mixer, permits of a proper proportioning of the materials, which has been demonstrated to be about 6% in weight of solid bitumen or mineral aggregate used, or about 1 gal. of the cut back or emulsion per cubic foot of crushed stone.

"With asphalt cut back, the best results have been obtained by using a material made from an asphalt binder, having a penetration of about 165, cut back with about 33% in weight of naphtha.

"With tar cut back, the best results have been obtained with a material made from a refined tar binder having a melting point of about 60°C., cut back with about 40% in weight of tar oils, of which at least 60% shall distil up to 235°C.

"A very satisfactory material for patching purposes is an emulsified asphalt containing about 65% of asphalt binder having a penetration of about 165.

"This material may be diluted with water if desired, and may be mixed with wet mineral aggregate when found in that condition. It readily separates from the emulsified state when combined with crushed stone in the so-called open mix.

"The resultant adhesive qualities of an emulsified asphalt appear to be better than can be obtained by the same asphalt in any other form.

"The only tangible reason advanced for this result is that water in the emulsion may carry the binder into the pores of the material or pavement to which it is applied.

"The patch made with emulsified asphalt hardens to a condition of stability much quicker than one made with cold oils or tars or cut-back binder that we have used, and is, for this reason, preferable to those materials for patching work on heavy-traffic highways.

"Very good results have been obtained with the cut-back tar cold-patch material, particularly on medium- to light-traffic highways, where the patching material is not thrown about by traffic to any great extent.

"In order to obtain efficient results in patching with a tar binder, it is necessary to make a so-called close mix, by using a graded mineral aggregate having a minimum amount of voids, which, however, will not permit the volatile oils to evaporate as fast, and the patch to become stable as quickly s may be obtained with asphalt emulsion when used in the open mix. It is, ccordingly, preferable when using tar to mix same with the mineral aggreate and leave in shallow piles for about 2 days before applying to the road urface.

"The necessity for using the close mix with tar binders is due to the fact hat tar products are more susceptible to the heat and cold than asphalts.

"In other words, if starting with the two materials of the same consistency t 60°F. the temperature is raised to that of a pavement on a hot summer ay, say 130°F., the tar is much more fluid than the asphalt and tends to ow away from the open minimum aggregate, and the open patch will show tendency to ravel. Again, when the temperature is reduced to that of a avement on a winter day, the tar becomes much more brittle than the sphalts and again the open patch with tar binder is much more liable to vel out than one made with asphalt binder.

"A comparison of the result obtained with the two materials, each of which ontains a quantity of the semivolatile oils sufficient to permit them to be pplied to the surface of the pavement at 60°F. as a surface treatment, emonstrates that the tar, by reason of its greater fluidity on a hot summer y, will penetrate the old pavement to a greater extent than the asphalts, d thereby serves more as a binder to the old pavement. It is for this ason that cold tars are generally used as the first and second treatment of water-bound macadam pavement. Subsequent treatments of heavy phaltic oils, carrying about 65% of solid bitumen, will give more efficient d lasting results if used conservatively, that is, if the successive treatments not follow each other too closely.

"When successive treatments are given every year as a dust layer to viate the necessity for patching, cold tar is preferable in that it does not

build up a mat on the surface of the pavement to the extent obtained with asphaltic oils.

"Provided a mat is built up with successive tar treatments, the same will generally lie flat and not shove under traffic, and develop a wavy and corrugated surface as is often obtained with too frequent surface treatments with asphaltic oils.

"This resulting difference is due to the aforesaid difference in consistency of the pavements at summer temperatures.

"The tar, being so fluid at summer temperature, appears to retain a smooth surface by the effect of gravity, while the asphalt simply softens sufficiently to permit the surface mat to be displaced by traffic, which displacement increases from day to day and often necessitates the entire removal of the old mat.

"Another factor to be considered in deciding upon the material to be used for the surface treatment is the condition of the old pavement.

"Where the old macadam is composed largely of small particles of crushed rock and dust, and is in a more or less loosened condition, and is subject tc displacement by traffic, a light asphaltic oil is preferable to cold tar foi surface treatments. The asphaltic-oil treatment develops into a mat oi carpet over the macadam which remains more or less plastic, even at low temperatures, and displacement of the macadam under traffic does not result in the shattering and the ultimate destruction of the mat to the extent obtained under similar conditions with tar treatments.

"Also for the same reason, asphaltic oils give the best results on pavements where steel-shod traffic predominates.

"The best results obtained with tar treatments are where the old macadam pavement is clean or free from dust and where the pavement is firm anc sound, and the stone fragments do not displace under traffic, and where motor-vehicle traffic predominates, also where a minimum amount of cove material is used in conjunction with bituminous material.

"Macadam pavements surface treated with tar are, however, much mor slippery for horse traffic in cold weather than those treated with asphalti oils.

"In my report of a year ago, I discussed to some length the subject of th extensive breaking through of many of the pavements during the sprin months.

"Referring to such report, it will be noted that the total area actuall broken through during the spring of 1916 was equivalent to 82 miles o pavement 16′ wide, and that the broken areas were distributed over man projects aggregating to a total of 1939 miles, of which an average of 4.2 % was broken through.

"During the season of 1916, about 75% of the total broken areas wa substantially repaired, and about 238 miles of the weaker pavements wer resurfaced.

"The spring of 1917 appeared to be a repetition of the previous year as t the amount of broken pavements.

"The result of a survey to determine the extent of the broken pavements when tabulated, indicates that the total broken areas were, however, bu 60 % of the total of the previous year.

"The total length of the various projects involved aggregated 2090 miles about 9% larger than those reported in the previous year. Of this tota length the equivalent of about 48 miles of pavement 16′ wide was broke up, or about 2½ % of the total length involved."

Asphalt, Topeka Mix, Amiesite, Etc.—The holes which develo in the bituminous-mixing-method-type wearing surfaces should b repaired as follows: Excavate the old material at the defective spo the entire depth of the course, so that the edges will present clear vertical surfaces, these surfaces and the exposed foundation to b swabbed or painted with hot asphaltic cement or paving pitch the hole then to be filled with a mixture similar to that used in original construction whenever practicable, using a sufficient quantit so that after consolidation or rolling (or tamping in case the exten of repairs is limited) the surface of the new patch will be ¼ above the adjacent pavement. In case no local mixing plant i

available, or the limited extent of repair does not justify the expense of treatment as above, holes may be repaired with the mixture of crushed stone and cold-patch asphaltic emulsion, as outlined for macadam surfaces page 558.

MAINTENANCE (CONCRETE PAVEMENTS)[1]

"Maintenance should be systematic and imperfections given immediate attention.

"**Cracks and Joints.**—The crack or joint should first be cleaned with a sharp-hooked pick and stiff brush, care being taken to remove all loose particles. If the opening is too narrow to permit cleaning in this manner, it should be cleaned with an air jet from an automobile tire pump. After thorough cleaning, tar should be poured into the crack in sufficient quantity just to flush over the edges. The tar should then be covered with coarse, dry sand. It will usually, be found desirable to remove old joint material to a depth of ¼ to ½" below the surface of the concrete, so that new repair materials will have a good bond.

"Care shall be taken not to pour the tar in such quantities that an unsightly wide strip is made on the surface. By bending the spout of the tar pot so that a long, narrow opening is provided, the tar can be poured in a very thin, narrow stream. It needs but a little attention to pour cracks so that a narrow ribbon of tar 1 to 2" in width is left.

"**Tar.**—Refined coal tar should be used, having a melting point (½" cube method in water) of about 100°F. The tar should be heated from 225 to 250°F. at the time of application and may be applied by means of a sprinkling can with spray nozzle removed."

"**Surface Pockets.**—A pocket in the surface, 1 to 3" in size, due to soft aggregates or the disintegregation of a lump of clay, or a piece of coal or wood, should first be thoroughly cleaned. It should then be filled with hard, small aggregates, ranging in size from ¼ to ⅜". Hot tar should then be poured into the opening until the tar is flush with the surface. Very coarse, dry sand should then be sprinkled on the tar immediately.

"A cold mix of small stone and emulsified asphalt has been successfully used for this type of repair work (see p. 558).

"**Slight Depressions.**—If for any cause a slight depression has formed, it can be coated with tar, very coarse sand added, covered with tar and the whole covered with sand and tamped into place.

"**Replacements.**—If it is necessary to cut a hole through the entire thickness of the concrete slab, gravel should be placed in the subbase and thoroughly rammed, so as to form a compacted base on which the new concrete will rest. Where water has been allowed to stand in such a place, it should be compacted after the water has been removed and just before laying the concrete. Before placing the concrete the sides of the opening should be painted with a mixture of neat cement and water.

"The consistency of the concrete should be sufficiently stiff to require considerable tamping to bring water to the surface so that it may be possible to ram it thoroughly into place. A small tamp, made of a 2 by 1" stick, 18" long, should be used to ram the concrete adjacent to the edges.

"After the concrete is rammed into place, it should be struck true to the surrounding surface. A repair made in this manner cannot be told from the old pavement after a few months use.

"A new patch should be kept moist for at least 4 or 5 days, and protected from traffic at least 10 days. By the use of Lumnite cement patches, traffic can operate within 24 hours."

Repair of Concrete Pavement with Quick-setting Cement.—During the season of 1925, the New York State Bureau of Highways under the supervision of County Assistant Engineer J. A. Small repaired the cement-concrete pavement of Highways 5422 and 5469 in Orleans County, by removing broken pavement and replacing with concrete of Lumnite cement. The total area replaced amounted to about 3000 sq. yd. On Highway 5422, 6% of the total area was replaced, and on Highway 5469 2% of the total

[1] Quoted from Portland Cement Association Handbook.

area. These roads were built in 1914 of 1; 1½ : 3 concrete and were 6″ thick, not reinforced. The areas removed varied from corner breaks of about 1 sq. yd. to patches extending the full width of pavement, 90′ in length.

The defective pavement on one-half the pavement was repaired before doing anything with the opposite side. Traffic was not held up or inconvenienced to any great extent during the progress of the work except at the site of the work, where one-way traffic only was possible. The total length of pavement under repair at one time was not more than ½ mile, generally less. Traffic was warned by portable signs placed at each end of the work and moved as the work progressed. These signs were of wood, 5 by 7′ and lettered as follows:

DANGER

REPAIR WORK AHEAD

ONE-WAY TRAFFIC

GO SLOWLY

When traffic was heaviest flagmen were placed at each end of the location of the work to direct traffic. The average traffic was about 150 vehicles per hour. As no serious and very few minor accidents occurred either to vehicles or to workmen, the method of carrying on the work was considered satisfactory.

The first operation of the work was the stocking of repair materials, sand and stone, at convenient places along the road shoulder. These stock piles were placed so that a considerable amount of repairing could be done with one set up of the mixer. These piles were placed not nearer the edge of pavement than 3′ in order to lessen danger to traffic. Cement was kept at a central storehouse and brought on the job daily as used.

The next operation was the removal of defective pavement. Only those blocks that were shattered and uneven, and corner breaks that were depressed below the level of the adjacent pavement, were removed. Blocks or areas that were cracked but not out of grade with adjacent pavement were not removed, as it was soon discovered that no bond could be made between the new and the old pavement and therefore there was no value or use in replacing old pavement which was cracked only with a new patch that would also show the joint between new and old.

The defective areas were broken up into one-man size pieces by means of air drills operated by an air compressor mounted on a four-wheel army auto trailer. The air compressor used on this job was an Ingersoll-Rand outfit, which operated two drills at the same time. The drill itself was a pavement breaker and was operated by the systems of splitting or wedging of a small piece of concrete at a corner or edge and then working back into the slab by breaking off successive small pieces. The gang consisted of two drill runners and two laborers. These laborers assisted in moving the machine and attended to spreading apart the broken pieces of concrete so that the next piece could be split off by the drill. In

general, the drill was some distance ahead of the concrete mixing gang so that the concrete in the areas broken up by the drill was left in place so that traffic could go over them until the gang engaged in removing this concrete came along.

This gang removed the broken concrete, trimmed off the edge of the pavement, and excavated the subgrade to a depth of from 7½ to 9″ below the top of the adjacent pavement. Usually it was impracticable to load the broken material on trucks at the time of removal on account of traffic using the other side of the highway. Consequently, this material was piled along the shoulder for removal later, or used to widen out the shoulder at the location of the patch if practicable.

In the beginning of the work no care was taken in trimming the edge of the old pavement after the drilling operation, as it was not thought necessary. It was soon discovered, however, that if any of the new concrete extended over the old pavement in a comparatively thin layer, it invariably cracked or spalled off, leaving a ragged edge to the patch. Consequently, thereafter the raw edge of the old pavement was trimmed by means of a mason's spalling hammer to a line having no sharp corners, no top spalls, and with the edge as near vertical as possible or slightly undercut.

No attempt was made to strengthen the subgrade under the patches of small area for the purpose of preventing them from being depressed under traffic. It was considered that to make the foundations of the patch stronger than the adjacent old pavement would tend to allow the old pavement to be depressed below the new. Any defect in the foundations, however, such as large boulders found under the old pavement, were removed and the subgrade made as nearly uniform as possible. In a few cases, also, a foundation filler of 4″ of stone screenings was placed under some small patches to determine if such treatment would have any effect in sustaining the new patch.

The location of open holes of small size in the pavement was indicated to the traveling public by means of broken pieces of concrete placed at the ends and side towards the center of the highway. Large repair sections were barricaded with lumber barricades. Also at both ends of the section upon which work was being carried on were placed barricades with warning signs. All openings or fresh-placed patches were indicated by red lights at night.

The operation of filling the open holes with quick-setting concrete was the next. On a large area to be filled, the mixer was set as near the opening as convenient, when the holes were smaller, but comparatively near together, one set-up was used for holes within 100′ or so of each side of the mixer. The mixed concrete was taken from the mixer to place by means of wheelbarrows. When the holes were farther apart and scattering, the concrete was loaded into a ½-yd. dump-cart trailer and hauled to place by means of a speed truck. The mixer gang consisted of one man operating the mixer, four men shoveling into the mixer, and three or four men wheeling. The mixture used approximated 1:2:4 mix. Stone was of the ¾″ or No. 2 size, New York State Standard. Sand was local and generally ran coarse. Water was hauled to

the location of the mixer in a tank truck trailer. This tank trailer was set up at the division shop and consisted of two 250-gal. army gasoline tanks mounted on a four-wheel army trailer. The mixer used was a one-bag Little Wonder with hoist.

In placing the concrete, a form was placed along the outer edge of the pavement and held in place by iron pins. The bottom of the excavations and edges of the old pavement were sprinkled with water. At first the edges of the old pavement against which the new concrete was to be placed were painted with a neat cement grout in hopes it would assist in obtaining a bond between the new and old. It was soon evident that no bond could be obtained strong enough to sustain the weight of traffic passing over the highway or even to prevent cracks forming when the concrete contracted upon setting. Therefore no attempt was made to obtain any bond Each separate patch must sustain the weight coming upon it In the case of two adjacent corner breaks it was found that no advantage was obtained in replacing the expansion-joint material between the two new corners. In fact, it was better construction to make the two patches continuous, thus giving a larger bearing surface on the subgrade. Care was taken to get mortar next to the old concrete and to spade the concrete under the old slab where necessary. The new patch was screeded so as to give a smooth-riding surface in connection with the adjacent pavement This made it necessary to place some patches across the pavement and some others longitudinally.

In curing the quick-setting Lumnite cement it was necessary to keep the concrete wet during the period of setting, at which time considerable heat is generated. Generally, within 5 hr. of mixing watering must be commenced, and the concrete kept wet or damp for about 15 or 20 hr. thereafter. This was done by means of a hand sprinkling pot. Water was kept in barrels at convenient intervals along the work. This sprinkling was done at night by the night watchman. Some difficulty was experienced in getting a man who would faithfully keep the pavement sprinkled. This man was on duty from 5 p.m. until 7:30 a.m. at which time the regular gang took up the work continuing sprinkling as long as the concrete showed any heat. Generally, sprinkling every 15 min for the period of from 5 to 10 hr., and at half hours or longer intervals thereafter, was sufficient.

On the small patches where the subgrade had become wet and softened by water from sprinkling, traffic was kept off until the end of the second day or at a time of from 24 to 30 hr. after the concrete was mixed. Side forms were removed and the opening backfilled with some non-porous material as soon as possible after the patch was cured to prevent surface water from standing along the edge and softening the subgrade. These precautions were necessary to avoid, if possible, the settling of the patch by the weight of heavy vehicles going over it. As the barricades and obstructions of the previous day's work were removed at the end of the next, or second day, the work as stated above did not extend more than ½ mile, where traffic was inconvenienced.

One result of this work is to indicate that no patch smaller than ıbout 10 sq. yd. should be placed. A patch of less area is too mall to sustain the weight that comes on it. Also a patch of 10 q. yd. can be reinforced, while it is difficult to reinforce a smaller atch.

On this job it was found that a gang of about 20 men was about ufficient to keep the work moving continuously. With this size ang, an average of about 40 sq. yd. of pavement per day could be emoved and replaced, the patches varying from 1 to 10 sq. yd. nd extending along the road for a distance of 1500′ or ½ mile. This gang would be distributed usually as follows:

- 2 men running drills
- 2 drill-running laborers as helpers.
- 4 men cleaning out broken concrete and excavating to required depth.
- 1 man setting forms.
- 2 men finishing concrete.
- 3 men shoveling sand and stone.
- 4 men wheeling concrete.
- 1 man operating mixer.
- 1 man watering concrete.
- 1 truck driver.
- 1 superintendent.
- 1 truck supplying sand and stone.
- 1 night watchman.

The cost of the work was as follows:

emoving old concrete and preparing opening for new patch	$1.19 per square yard
eplacing with new concrete, labor, mixing, placing, finishing, curing	$2.19 per square yard
Iaterial for replacing, including delivery on the work	$2.73 per square yard
Total cost per square yard	$6.11

Block Pavements.—Block pavements of brick, stone, asphalt, tc. properly constructed should not require repairing for a conderable term of years. Cracks which develop should be grouted ith hot paving pitch or asphalt binder. Areas which settle, ıereby breaking the bond of the grouted joints, resulting in crushıg or cobbling the blocks, should be taken up, the sand cushion formed, all sound blocks cleaned and relaid and turned over here necessary, any broken blocks replaced by new whole ones, ıd joints then grouted with Portland cement grout preferably, if ıe original pavement was so constructed, otherwise the joints may poured with hot paving pitch. It should be noted that repairs ith fresh cement grout require protection by barricades for about week, so that such repairs should be confined to one side of the ıvement in long stretches, leaving the other side available for affic; where the repairs are limited in extent and barricades are pecially undesirable, the patch may be covered with 2″ of earth ıd further protected by planking during the time required for the

grout to set. Where joints are poured with paving pitch, traffic need be diverted only during the time of actually making the repair; this is a decided advantage.

Rigid-pavement Shoulders.—Observation demonstrates that horse traffic on steep grades leaves the pavement and seeks the earth shoulder, so that, so far as practicable, these shoulders should be improved by widening, and by graveling or covering with broken stone to avoid excessive rutting; also that on sharp curves the tendency of motor vehicles is to cut close to the inner edge, making it well for this reason to stone or gravel the shoulders at these points.

Along the edges of the rigid types of pavement, block and concrete especially, traffic usually develops a deep rut which if neglected becomes dangerous to rapidly moving traffic; this rut should be kept filled with gravel, broken stone or cold patch. Excess material when removed from the shoulders should be so disposed of as to widen embankments and flatten slopes.

Snow Removal.—On main roads between large cities, snow removal in winter has become part of the regular program. In many districts automobile trucking relieves rail congestion and is needed even more in winter than in summer. The maintenance departments are in a position to handle this work with their organized forces and equipment which are idle at this time of year, and the necessary expense is certainly worth while to make the main road passable for trucks the year round. The only way successfully to handle snow is to start shoveling as soon as a storm starts and keep working. If bad drifts are permitted to form, it is very expensive to clear the road. Snow fences help to prevent drifting. In Monroe County, New York, the cost per mile per winter to keep the main roads passable for motors ranges from \$50 to \$100. The usual equipment consists of trucks or caterpillar tractors equipped with special plows.[1] Hand shoveling is at times necessary when bad drifts form. A permanent fund of \$75 per mile per year is proposed with any unexpended balance for easy winters carried over for use in exceptionally hard winters. Four hundred miles are to be kept open in this county and the popular approval of expenditure for this work assures a continuation of this phase of highway maintenance.

MAINTENANCE OF EARTH, SAND-CLAY, AND GRAVEL ROADS

The maintenance of these roads consists in keeping the grass and weeds cut, the ditches clean, culverts clear, overhanging trees trimmed, and the surface of the traveled way scraped and dragged. One shaping with a blade road machine in the spring generally is all the heavy work required, the rest of the work being done with road drags, hones, planers, etc., at frequent intervals during the balance of the year. On sand-clay and gravel roads, surfacing material is added to fill holes and ruts or better the wearing surface.

There are two general systems: the contract system, which lets short strips of road not over 4 miles in length to farmers along the

[1] Each should be able to care for 15 to 25 miles of road with occasional extra help.

road, and the patrol system, which is taken care of by a steady patrol gang which handles from 10 to 20 miles. The contract system is explained in the quotation from the 1917 "Year Book" of the American Highway Association (p. 453). The patrol system is referred to throughout the chapter in various quotations.

Earth Roads.—Road machine blade scrapers are familiar to all readers. The road hones, planers, etc., are not so well known and their construction is shown in Figs. 179 and 180. Steel drags can now be obtained. Their use in earth- or gravel-road maintenance is explained in the following quotation from the "United States Forest Road Manual."

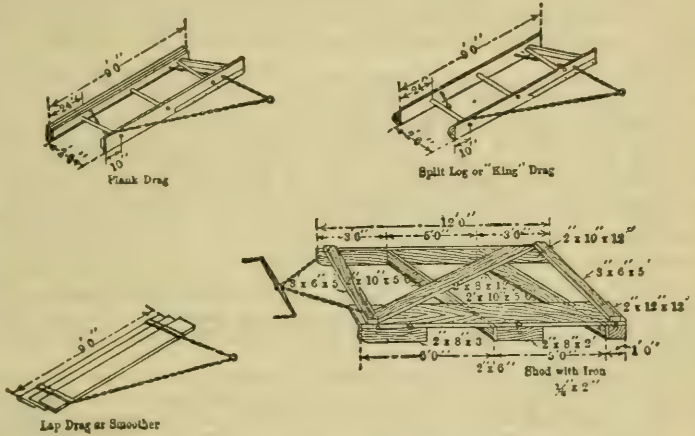


FIG. 179.—Road drags and planers.

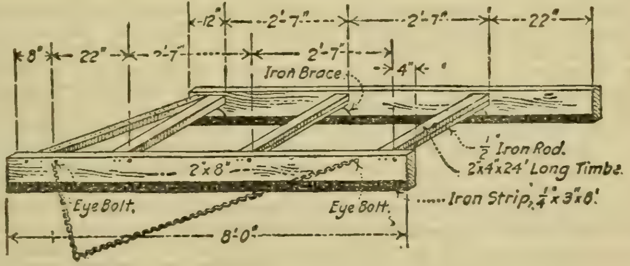


FIG. 180.—Road drag.

EARTH-ROAD MAINTENANCE (U. S. FOREST ROAD MANUAL)

"Maintenance is the most important item of work to be considered in ad management. The smaller allowances for systematic maintenance, as ey are being included in the annual road budget alongside the unlimited umber of those for periodical repairs, tend to give it a place of least consideration, and again its consideration and planning are evaded as much as ossible for these are the never-ending consideration of continuous annual ork and expense. It is always admitted that the degree of efficient use we rive from anything constructed for practical utilization depends on the nount of effective maintenance it receives. Therefore, roads which are

most widely used and exposed in all their parts to the worst of elements relatively should receive the highest degree of such attention, and, moreover, the higher the type of construction and the more it costs, the more marked attention will it require.

"However, it is most gratifying to find that the old ideas of taxpayer and user are rapidly disappearing, making way for the installation of practical system for the efficient retention of the better roads—as they are now being constructed. We are gradually beginning to learn that the stability and usefulness of a road are not forever established—even when the best of supervision and authorities declare and approve or have made the construction strictly up to the standard and with ample drainage provided—bu that each mile of construction should be followed immediately with a mile of maintenance. Besides eliminating the difficulties and discomforts o travel—which seem only a benefit to the traveler, but which are in reality an economical benefit to everyone, directly or indirectly—maintenance wil do away with all the worries to the management and effectively prevent s much of this misapplied criticism to construction features. Finally the good results of maintenance encourage more road building, whereas its lack discourages it.

"There is no type of road that can be considered permanent, and a earth road or one bedded in the natural material—which is wholly as impor tant as the higher-grade roads, or even more so—is the cheapest to maintai in its original condition. The complete maintenance of an earth road mean simply the retention of the drainage facilities that were provided in a com pleted and properly constructed piece of road work. Furthermore, th experience and the attention given to the road in constant maintenance wi show where ample drainage was not sufficiently provided; and again showin its importance, constant maintenance secures this necessary drainage wit the least costs and at the proper time—before serious damage is done an heavy repair costs result. The time to begin the maintenance is immediatel after the road is constructed, and its degree of efficiency will depend on wha in the way of money or assistance, is constantly provided or made availab to meet sudden contingencies. The work must be done at the right tin and in the right way to get the best results.

"Ample drainage begins with taking the water off the road and continu with taking it along the road and away from the road. Constant maint nance by dragging secures this primary step in the drainage system, ar also a hard and smooth surface for travel. The dragging preserves tl crown, which is kept in the traveled way for no other purpose than to she water. It then follows that this water will be taken away from the roa through the further efforts of constant maintenance in keeping the ditch and culverts open.

"To maintain a certain road or set of roads properly and economicall an organization for doing the work should be effected. On a country mountain road a patrol consisting of two teams and two men for one pa and one team and one man for the other part of the season should be ab to care for 15 to 20 miles. It will be found though that a newly construct road will require heavier maintenance for the first year or two, thus reduci the number of miles for this patrol. One or more such outfits could applied to a longer road or a larger system and kept under the same supe vision. These patrols keep the ditches clean and the culverts open, ha surfacing materials, *i.e.*, clay onto sandy portions and sand or gravel on clay, keep the right of way open to sun and wind, and are on hand to dr the road after each rain. Two teams are provided only in cases where the is no extra help available along the road to assist in the dragging, otherw one team would be sufficient. However, if the teams are government owne two teams should be used, as the added costs for the extra team are sm and will in most cases prove cheaper than hiring. The two teams can used on one drag or two, depending on the ruling grades in the road.

"In early spring when the winter snows are going off, the supervisor a such extra assistance as is necessary should be made available early to s that the snow water is being cared for, that is, running down the ditches a into the culverts, and not down the wheel tracks and over the banks of t road. Later he should have a small gang of men making the necessa repairs that might occur while the frost is coming out of the ground, a from wash and water breaks. A light grader should be at hand, especia on side-hill roads, to clean the ditches of material broken off or rolled do the banks and to restore badly depleted crowns, after which the drag can used for the remainder of the season to preserve this perfected condition.

"A good foreman for this should be a man who, as well as being able to take a hand in the work, should be able to plan the work and keep in touch with the maintenance needs and move his men economically to the first necessary piece of repairs.

"Dragging is the cheapest and most effective method of maintaining roads constructed of earth, topsoil, sand clay, or gravel. The drag is a very simple and inexpensive implement and when used properly gives surprising results.

"Properly used and at the right time, the road drag performs four distinct offices: (1) By moving at an angle to the traveled way it tends to produce or preserve a crowned cross-section; (2) if used when the material of the surface is not compact and hard, it tends to reduce ruts and other irregularities in the road by moving material from points which are relatively high to those which are relatively low; (3) when used after a rain, it accelerates the drying out of the road by spreading out puddles of water and thus increasing the surfaces exposed to evaporation; (4) if the surface material is in a slightly plastic state, dragging smears over and partially seals the so-called pores which naturally occur in earthy material, and thus makes the road surface more or less impervious to water.

"If used improperly or at a wrong time, the drag may do actual injury to a road. Dragging a very dry road, for example, serves to increase the quantity of dust and may do additional damage by destroying the seal produced during previous draggings. If, on the other hand, the road is very wet and muddy, the irregularities in the surface are likely to be increased rather than diminished. The common defect in road dragging is to regard the road drag as a road-building tool, and to expect one or two trips to put the road in shape for the season."

Notes on Maintenance

"1. In filling bad ruts and mud holes, it is best to use the same material that the roadbed is composed of, otherwise an uneven surface will result. Oftentimes, of course, the roadbed of clay can be improved by scattering sand or gravel over it more or less evenly, or, if the roadbed is of sand, by the same use of clay, but the ruts should not be filled with these applications. Filling with rock will effectively close a mudhole, but the next season will find two more mud holes, one on either side of this hard place formed by filling the first.

"2. After light snowfalls on side-hill roads, the inside ditches should be cleared of the snow immediately in order that the water from the melting snow will run down the ditches instead of the wheel tracks. This is especially necessary where steep grades occur to prevent heavy wash and loss of crown in the traveled way, and water breaking over the outside bank. As the snows are usually light, this can be done by drawing the drag down the ditch with a large skew angle or, better, with a small ditch cleaner, the *A*-drag or go-devil.

"3. In a grazing country very often it occurs that salting grounds have been used near or along the roads. These should be removed, for cattle climbing up and down the banks and walking along the ditches can cause considerable unnecessary damage to the road. During the season of cattle or sheep drives, the men on maintenance should see to it that the herds or bands, if they have to use the road, use the traveled way and not the banks, and do as little damage as possible. If serious damage is done, they can make immediate reports, as owners are obligated to repair such damages on public roads.

"4. Outer bank slopes of earth that are continually eroding should be protected by sowing to grass, or any other plant that will mat and not be objectionable to occupants of lands along the road.

"5. Keep the ends of the culverts free from drifting weeds and débris and clean the catch basins of silt and other deposits.

"6. Remember that the chief repairs should be looked after in the spring when the soil, moist and easily worked, will compact readily under the drag and traffic. There is little use in attempting to do much to the roadbed proper in July and August, for the soil is so dry that it is difficult to shape it properly and most of that moved will blow away in the first wind."

Notes on Dragging

"1. Use the drag often and if the very best results do not come at first trial, do not quit. First-class results can be attained.

"2. Dragging is always done after rains, melting snows, or thaws, just after the ground has lost its stickiness, when the material will slide easily along the face of the drag and pack well; but not when it becomes dry in any one place. Different road surfaces and varying conditions will demand different times of application, the knowledge of which will come through faithful and persistent use and observation.

"3. It requires a careful and skilful operator to get good and quick results, one who knows or can learn how to hitch to it, and where and how to ride it. Hitch so that the drag will travel at an angle of 45° with the center line of the road, and do not try to cut too much material at one operation. The amount moved depends wholly upon the length of hitch and position of driver. A long hitch will move more earth than a short one. When a hard spot must be cut, the driver throws all his weight on the front blade: when a low place must be filled he moves back. These operations on patented steel drags are facilitated by changing the angle of the blades from a vertical. Step quickly to the opposite end of the drag from which you wish to deposit material into low spots.

"4. Drive the team at a walk and ride the entire distance. The drag should begin at the ditch line and proceed toward the center or crown If the crown becomes too great, reverse the skew angle of the drag. Do not try to drag too wide a section at one operation.

"5. Do not try to drag too long a section. So much depends on the time the drag is used, that there is danger of dragging the road too wet at one end and too dry at the other. Learn to select those sections which dry before the others and drag them first.

"6. Drag the road during or directly after one of the light snowfalls, just before it freezes up for the first time, as it will be in better condition to go through the winter and better able to shed water during the spring thaw

"7. Very little improvement will be noticed after the first trial, and many trips will have to be made the first year after construction. The second year less dragging will be required and the road ought to improve continually

The following quotation from the 1917 "Good Roads Year Book" shows the Kentucky methods and approximate cost of maintenance

"Maintenance by dragging is most successful when well organized. The results obtained by good management in Hopkins County, Kentucky, are frequently cited as indications of this, and for this reason the following account of the work there is quoted from a report by the Kentucky Department of Highways.

"In 1912 a county engineer was appointed. The county roads were measured under his supervision and 2-mile sections designated, and in January, 1913, drags were started on about 100 miles of the county roads This original contract was only for dragging the roads, which work was to be done four times between Jan. 1 and Apr. 1, at a cost of $10 to $12 per mile As the sections dragged were not continuous, the citizens at once appreciated the difference between the maintained road and that which was not maintained. Consequently, the next contract, which called for dragging and also for cleaning the ditches for 6 months, until November, 1913, resulted in contracts for 150 miles of road and at a reduced cost. In November, 1913 a contract substantially like that now in use was adopted and the time of the contract was for 1 year, or until November, 1914. Over 200 miles were maintained this year at an average cost of $28 per year per mile. For the year from November, 1914, to November, 1915, the benefit of the maintained roads was so well understood by the citizens that 560 miles were under contract at an average cost of $24.35 per mile per year.

"In November, 1915, a 2-year contract was entered into, which the county may revoke for a non-performance of the obligation at the end of the first year. About 520 miles are now under contract, at prices ranging from $12 to $40 per mile per year, the average being $22.10. It is expected this mileage will soon be increased. Originally, a contractor was allowed to have charge of 8 miles, but now he is not allowed to contract for more than 4 miles of road. Under the 1915 contracts, the contractor must trim the branches which overhang and interfere with travel on the roadway; keep the ditches clean, free from obstructions, and at all times capable of carrying the water. He shall, by June 1, each year, grade the roads with dump scraper, grader, drag, and ditcher, or in any way he may see fit, so that the center of the roadway shall be crowned so that the water will flow from the

center of the road to the side ditches, and at no place will the water stand on the road or run down the road. The road shall be dragged from ditch to ditch at each dragging, when the road is wet, but not sticky.

"A record of the number of draggings is kept by the county engineer on cards which, before mailing to the contractor, are countersigned by the rural route carrier or a reliable citizen. The contractor also hauls material and constructs all culverts and bridges of 10′ span or under, and keeps the approaches to, and the floors and abutments of, all bridges and culverts on his road in good traveling condition. An analysis of these contracts shows that where the contract has been faithfully executed there is a decrease each year in the cost per mile, mainly because the farmer contractor has learned from experience that continuous maintenance makes a lower cost of time and labor each succeeding year."

Cost.—The cost of earth-road maintenance ranges from $20 to $200 per mile per year. A fair average is approximately $50 to $100 under light volume of traffic per mile per year for ordinary farming country and $100 to $200 per mile per year for mountain roads.

Sand-clay Roads.—The methods and character of work are the same for the sand-clay maintenance as for ordinary earth roads. The cost is generally less. The following quotation from the Alabama State Highway Report indicates the usual procedure.

Sand-clay Roads

"No cheap road can be maintained as easily and at as small an annual cost as a well-constructed sand-clay road. It responds readily to a road machine and the surfacing material is usually very convenient. Like all others, though, it is neglected until extensive and expensive repairs become necessary. If a sand-clay road which has been intelligently constructed is kept dragged at reasonably frequent intervals, say three times a month during December, January, February, March, and April, and during rainy periods in the other months, it will give excellent service and serve all practical purposes. If too much sand is in the surfacing material, the road will tend to ravel or disintegrate and it becomes necessary to add a small amount of clay to the sandy section. A thorough harrowing should then be given the surface, after which the road should be thoroughly machined or dragged until the proper cross-section is obtained. Likewise, too much clay may develop in wet weather and the addition of sand becomes necessary. Sand can be incorporated in like manner as the clay. In very wet weather, traffic will incorporate the sand fairly well and it frequently becomes necessary to add sand to prevent slipping, when artificial mixing would be difficult."

Gravel Roads.—Gravel roads require patrol maintenance for good results. The road should be shaped with a road machine blade grader in the spring while soft and plastic and kept in shape by dragging. Gravel must be added continuously to fill holes and ruts. Shoulder, ditch, and culvert routine cleaning is the same as for any maintenance.

The following quotation is from "Instructions to Patrolmen" in New Hampshire, which is famous for its gravel roads.

"Each patrolman must supply a horse and dump cart, shovel, pick, hoe, rake, stone hook, ax, iron bar, iron chain, and tamp. Special tools are furnished by the State Highway Department.

"One dragging in the spring is worth two in the summer. It is better to drag a mile of road several times and get it in good condition than to drag 2 or 3 miles and not finish any part of it. Don't drag a soft section when it is so wet that the first vehicle to pass will rut it all up. First fill the holes and ruts with new material and then drag as the surface dries out. Every patrolman should have material dumped in small piles along the side of his

section so that on a rainy day he can at once fill all holes and ruts in which the water is collecting.

"When the weather is unsuitable for dragging, as during a dry spell, all patrolmen should cart on all the new material possible in order to fill all ruts and holes and resurface worn sections. Carting is very essential during dry periods and should never be neglected. Whenever a patrolman is in doubt as to what to do next, the general rule is to cart new material, for all roads are wearing out under travel and it is necessary that the surface be continually renewed to take the place of the old material that is thrown out as mud or blown away as dust.

"Save all the sods, leaves, rubbish, stones, and refuse that you clean off your road, and dump this waste material in places where the bank is steep so that by flattening the side slope there will be no need of a guard rail; or dump the material back of a present guard rail so that later this guard rail can be removed."

The necessity for patrol maintenance is shown by the following extract from the Iowa Specifications.

MAINTENANCE OF GRAVEL ROADS

"County engineers' and supervisors' attention is called to the fact that both Class *A* and Class *B* gravel roads require constant and systematic maintenance at all times. Special attention should be given such roads for the first year following their construction. During this period the gravel is sure to become rutted, wavy, and scattered if it is not maintained in the most careful manner.

"Hauling gravel and dumping it on the road does not produce a gravel road. The most important part of the construction work lies in the attention which the road receives while the gravel is being compacted. A road newly surfaced with gravel is nothing but a possibility. The success or failure of such a possibility depends very largely on the attention which it receives during its first year. The frequent use of a planer or blade grader will prevent the formation of ruts and waves. This work should be done while the gravel is wet, as better results will be secured.

"The scattered gravel should be brought back on the surfacing and the earth shoulders built up to hold this material in place. Additional gravel should be added to replace that worn away and to fill and depressions due to settlement.

"The Commission strongly urges that the patrol system of maintenance be adopted for all gravel roads. The patrolman should spend all his time on the road. It is only by such a system that definite responsibility can be fixed. Patrol maintenance should extend not only over the first year after the gravel surface is placed, but also throughout the succeeding years. It should extend to the side ditches, earth shoulders, culverts, and all other parts of the road as well as to the gravel surfacing.

"While the patrol system of maintenance is urged for all gravel roads, it is absolutely necessary for Class *B* gravel roads. These specifications have been prepared with that idea in mind.

"The Commission will approve the construction of Class *B* gravel roads on the county system only on condition that an adequate patrol maintenance will be established promptly after such road is placed in service," see page 353 for sections of Iowa Gravel Roads.

IOWA HIGHWAY COMMISSION.

GRAVEL-ROAD MAINTENANCE WITH "SPRING SCRAPERS"

Method employed in Kent County, Michigan, described in paper presented Feb. 14, 1923, at ninth annual Michigan Conference on Highway Engineering.

By OTTO S. HESS

Road Engineer, Kent County

"The system of maintenance which will be outlined in this paper has been developed in Kent County during the past 2 years, and the ensuing remarks will apply more particularly to Kent County rather than to the state as a whole.

"While this system will undoubtedly operate to good advantage in a great many counties, it is not advocated by the writer as a cure-all for the many difficulties which are encountered in the maintenance of gravel roads.

"Highways of Kent County.—At the present time, Kent County has 252 miles of improved gravel roads on the county road system. Of this mileage, 90 miles lie on the state trunk lines, and the remaining 162 miles are county roads. In the early maintenance season of 1920, all of this mileage was taken care of by teams hauling light graders or floats. About this time, the county tried out a maintenance machine which was new at that time but quite well known throughout the state and even outside the state at the present time. This machine is the spring scraper which is used as a truck attachment and operates as a blade scraper underneath the middle of any truck.

"The first 'spring scraper' was so successful that the team patrols were gradually replaced by the so-called truck patrols, until at the beginning of the maintenance season of 1922 all of the teams had been replaced and the entire mileage of 252 miles of gravel roads was being kept smooth by nine trucks with scraper attachments, making an average of 28 miles per truck.

"Work of Truck Patrols.—Under the present system, Kent County is divided into four maintenance districts. The trucks are operated from a central point in each of these districts. A very thin layer of finely screened gravel is kept on the surface of the road at all times. By scraping this surface often enough it has been found possible to maintain a surface which is smoother to ride on than most pavements. The number of times per week or per day which is necessary to scrape the surface in order to keep it in this condition is dependent on the weather and the volume of traffic, but more particularly on the volume of traffic. The amount of scraping, and, consequently, the cost of maintenance have been found to be very nearly in direct proportion to the volume of traffic using the road.

"The type of trucks which has been found to be the most economical in Kent County are those in the 2- to 3-ton class. These trucks carry a 10′ blade, which is placed under the truck in a diagonal position, and travel at a speed of from 8 to 12 miles per hour. The blades are 10″ wide to start with, but are worn down with about 2 weeks steady use to a width of 3 or 4″.

"Each truck on scraping work is able to travel from 60 to 90 miles per day. Each truck scrapes a path approximately 9′ wide. With reference to the quality of work done, it can truthfully be said that the old team patrol system was never able to keep the roads so smooth as they have been maintained by trucks. In fact, the gravel roads of Kent County have never been in so good condition as they were in 1922, when they were maintained entirely by trucks.

"Saving Effected by Substituting Trucks for Teams.—Some idea of the saving which can be effected by substituting trucks for teams can be obtained by comparing the daily costs of each. In actual practice it was found that one truck would, on the average, replace six team patrols. In 1922, teams with drivers cost \$6 per day, making \$36 per day for six team patrols. One truck could be hired, with driver, at \$20 per day. This shows a direct daily saving on the pay-roll of \$16 per day per truck. Assume that the number of days worked during the season was 200 and we have: 200 days × \$16 × 9 trucks = \$28,000, which is the direct pay-roll saving during 1922. As a matter of fact and record, the actual saving was about \$30,000 since Kent County operated its own trucks at about \$15 per day instead of hiring them at \$20. As a further saving which is effected by the scrapers, it should be remembered that it is necessary to buy and maintain only one scraper as compared with six outfits of teams. Another advantage, which is by no means unimportant, is the fact that the trucks can haul gravel or other materials and scrape the roads at the same time. This is a feature which saves many thousands of dollars in a year's time, and is not obtained by any other type of road maintenance equipment in use today.

"Cost of Maintenance.—In order that one may obtain some idea of what this maintenance work costs, the following table has been prepared, showing the cost per mile, volume of traffic, and cost per vehicle mile for all of the gravel roads on the state trunk-line system in Kent County:

Maintenance Cost of Gravel Road on State Trunk-line System in Kent County

Section	Number	Mileage	Total cost	Cost per mile	Average daily traffic	Number vehicle miles	Cost per vehicle mile
13	1	7.50	$ 9,139.50	$1,218.60	1,791	2,686,500	$0.00340
13	3	7.00	10,634.76	1,519.25	1,810	2,534,000	0.00419
13	4	5.00	8,235.54	1,647.11	2,025	2,025,000	0.00460
13	5	14.50	12,077.29	832.11	838	2,430,200	0.00496
37	8	2.00	1,414.41	707.20	594	237,600	0.00595
37	10	5.50	3,819.89	694.53	594	653,400	0.00584
16	14	14.00	17,358.33	1,239.88	1,305	3,654,000	0.00475
39	16	11.50	5,836.71	507.54	594	1,366,200	0.00427
39	18	1.50	446.22	397.48	680	204,000	0.00218
44	20	13.50	12,380.47	910.77	1,079	2,913,300	0.00415
66	15	2.50	958.55	383.42	.....	No traffic count	
54	23	14.50	9,610.89	662.82	.....	No traffic count	
Totals, averages.....		99.00	$91,912.64	$ 928.31	.....	18,704,200	$0.00435

"In explanation of the table, the writer would advise that the total numb of vehicle miles for any section was obtained by multiplying the average dai traffic (as determined by a traffic census taken in July and August) by 20 and then by the number of miles in the section, assuming that twice tl average daily traffic in the summer would represent the total traffic for tl year. This shows that the average cost per vehicle mile on the state trun line gravel roads was a little less than a half cent."

Cost.—F. R. White, Road Engineer of the Iowa Highwa Commission, supplies the following information in regard to tl construction and maintenance cost of about 400 miles of Class gravel roads (see Fig. 115 p. 353). These roads are constructed a cost slightly above $1000 per mile (1913). The cost of maint nance depends very largely on the volume of traffic and the locatic of gravel. Where there is an average of 200 to 300 vehicles p day, however, and the gravel can be obtained within 3 miles of tl road the yearly cost of maintenance is about $150 per mile (1916

In New York State where the roads are oiled to care for a som what larger volume of traffic, 200 miles of high-class gravel roa cost approximately $700 per mile per year to maintain.

A fair average maintenance cost per mile per year for doubl track gravel roads is probably from $200 to $300 under fairly hea traffic (300 to 400 vehicles daily).

CHAPTER VIII

RECONSTRUCTION

Resurfacing or reconstruction is resorted to when normal maintenance methods with reasonable yearly expenditures fail to keep the highway in proper condition for traffic. Economic limits of yearly maintenance costs and maximum permissible degrees of roughness were discussed in Chap. 7 (pp. 547 to 552).

Reconstruction includes the restoration or improvement of pavement conditions in regard to strength, width, and perfection of surfaces, the retention of a safe and convenient grading section, ditch to ditch, and sometimes considers alignment changes to increase safety and reduce objectionable grades. Relocations in the matter of alignment and grade were discussed in Chap. II. Existing practice in pavement reconstruction generally fulfils the principles of improvement of surface and pavement width but often neglects the item of the retention of a safe grading cross-section ditch to ditch. That is, proper shoulder and ditch work is often slighted, which results in added danger from narrow soft shoulders and deeper ditches. Existing ditches are often deepened to get shoulder material instead of providing an item of borrow excavation for suitable gravelly soil for the necessary shoulder fills.

The cost of reconstruction programs is affected by type selection and by the promptness with which roads are treated when they show the preliminary evidence of some weakness. Delay, due to shortage of funds, is probably the most active cause in raising reconstruction costs (see p. 582).

Figure 181 shows typical reconstruction designs, state of California.

Economic Type Selection.—Reconstruction programs are overshadowing original construction in many of the states having state-aid programs over 15 years of age. The economic selection of pavement type for reconstruction is a proposition entirely different from the selection for original construction. Economic reconstruction must utilize to best advantage the existing pavement. To do this, it is generally undesirable to change the type of foundation, although it is often desirable to strengthen the foundation and better the surfacing, particularly to get rid of oiling maintenance on main roads; that is, if the existing road is of macadam type serving traffic of Classes II*A*, II, or III, it is rarely desirable to change to the rigid type of pavement, although it may be desirable to strengthen the existing macadam and surface with an asphaltic concrete or block pavement in order to eliminate the oiling nuisance. If an old

macadam practically shot to pieces serves Class I traffic, it is evidently desirable to change type.

All original roads become in time merely foundations for easily repaired renewable surface courses which meet the demands of

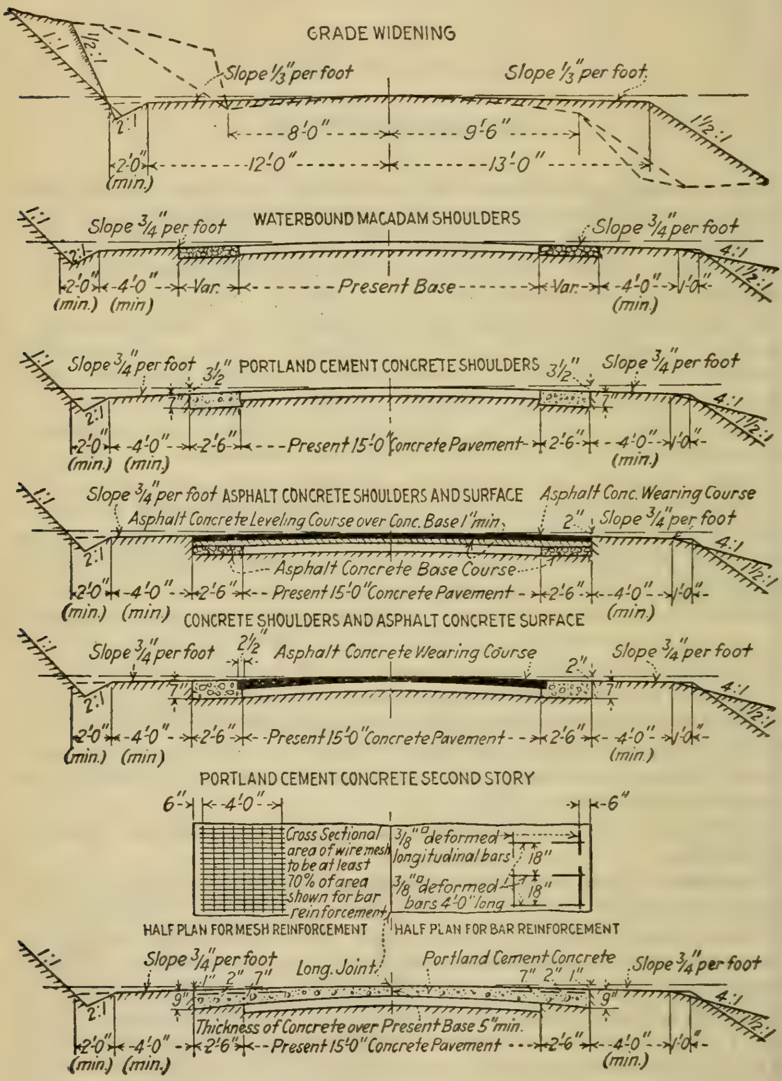


FIG. 181*A*.—Reconstruction sections, state of California 1926 Widening and thickening old state roads.

traffic. Adequate foundation strength can be achieved either by sufficient depth of macadam or sufficient depth and strength of cement concrete. After adequate foundation strength is attained

by either method, satisfactory surfaces can be maintained at about the same cost per year. As discussed in Chap. VI, Design, the thickness of cement concrete foundations is about the same whether laid on old macadam or new grading; where an old macadam pavement exists and the reconstruction type is changed from a flexible foundation to cement concrete, most of the value of previous pavement work has to be thrown away which usually raises the cost of such work way beyond the method of retention of foundation type with necessary additional strengthening and improvement of surface.[1] To illustrate briefly from Division 4,

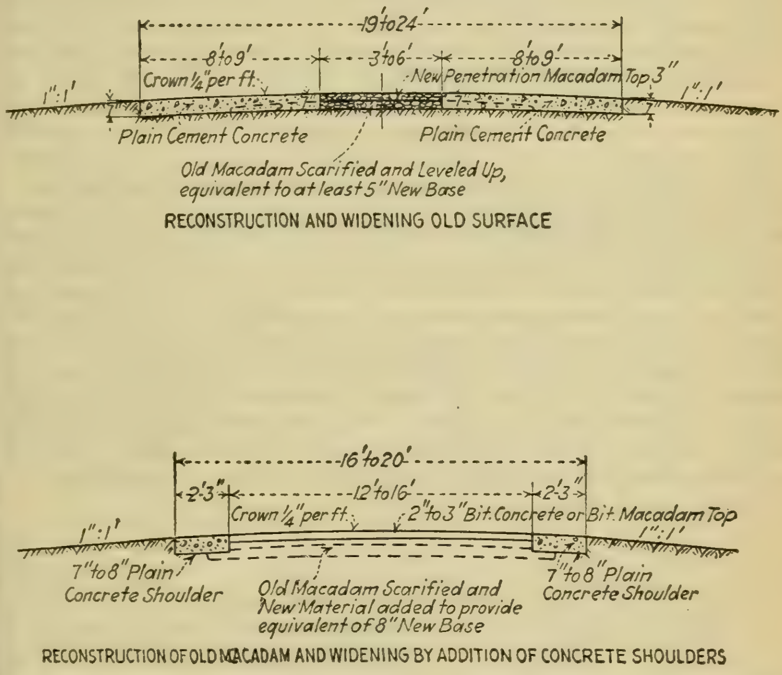


FIG. 181*B*.—Reconstruction sections. U. S. Bureau Public Roads 1926.

New York State, 1922 cost conditions: Old, firm, water-bound roads serving Class III traffic can be resurfaced with water-bound macadam for about 80 cts. per square yard, or with penetration bituminous macadam for about $1 per square yard. If type is changed and the thinnest, cheapest rigid pavement possible is used, 6″ reinforced cement concrete, it costs about $2.70 per square yard. A good many of the old water-bound roads are too weak

[1] The depth of concrete bases or pavement laid on top of an existing old macadam road is about 1″ less than where laid on ordinary earth subgrade (see Chap. VI). This reduces the cost of the concrete pavement about 50 cts. per square yard, whereas the old macadam, if utilized to full advantage as part of a flexible-type pavement, is worth about $1.50 per square yard.

for modern traffic and require additional strengthening over and above a new 3″ top. This additional depth rarely requires more than a 3″ to 5″ middle reinforcing course, costing from 40 to 70 cts. per square yard. For such roads, retention of water-bound type with adequate strength costs about $1.20 to $1.50 per square yard and adequate strength with improved penetration-bituminous macadam top costs from $1.40 to $1.70 per square yard, while change of type costs at least $2.50 to $2.70 per square yard. Under this class of traffic, the difference in first cost far outweighs the minor difference in yearly surface maintenance of the two types (see Maintenance Costs, p. 520).

Under Class II and II*A* traffic, firm macadams can be resurfaced with penetration macadam for about $1.20 per square yard, and with asphaltic concrete or small cubes for from $1.50 to $1.80 per square yard. Change of foundation type costs about $2.70 to $3.40 per square yard. For the weaker macadams, the cost of proper reconstruction, using necessary additional reinforcing middle course, probably averages about $1.90 per square yard for penetration macadam and about $2.20 to $3 for low-maintenance-cost surfaces, such as asphaltic concretes and stone or brick cubes. The advantage still lies with retention of foundation type, considering the sum of reconstruction costs and yearly maintenance.

Under Class I traffic, the advantage falls on the side of change of type, and for these roads there is no hesitation in adopting the policy of rigid foundation type. In this territory, however, there are at present 860 miles of improved roads of all types serving all classes of traffic. Table 110 below indicates the relatively small mileage on which it is desirable to change foundation type, namely, about 5 to 15% of total mileage at present constructed; but this percentage may be radically changed by delay in necessary reconstruction (see p. 583).

TABLE 110

Class of traffic	Flexible type of foundation, miles	Rigid type of foundation, miles
Class I	42[a]	34
Class II*A*	106[b]	72
Class II	280	58[c]
Classes III and IV	220	48[c]
Totals each type	648	212
Grand total, 860 miles		

[a] Mileage on which it is desirable to change foundation type, 5% of total.
[b] Mileage in the doubtful class 12% of total. Total mileage on which there is some justification for changing type, 17% of total constructed.
[c] Suitability of original design doubtful.

Effect of Delay in Reconstruction on Final Cost.—The costly result of delay in resurfacing at the proper time is shown by the following official report.

Apr. 9, 1923.

"Mr. ——————,
Division Engineer,
Rochester, N. Y.

"Dear Sir:

"Find attached design report for the proposed Federal Aid Reconstruction of Monroe Avenue, Road 94, Sta. 129+27 to 219+80.4 (1.71 miles).

"Two estimates have been made. Design 1 calls for an 18′ width of cement-concrete pavement 8 by 6½ by 8″ thick. Mesh and bar reinforcement with special shoulders 3′ wide on both sides, constructed from the old macadam excavated from the center of the road. Design 1 is estimated to cost $78,000.

"Design 2 calls for an 18′ concrete pavement 7″ by 6½″ by 8″ thick with 2′ width of gutter and a curb 7″ high along the left side of the pavement, Stas. 129 to 184 where the Rochester & Eastern Electric Ry. tracks are located close to the pavement edge. A special shoulder 3′ wide constructed of excavated macadam is used on the right side. From Stas. 184 to 219 the design remains the same as for the first case. This design gives an effective pavement width of 20′, Stas. 129 to 184, and provides a raised curb protection next to the track. Design 2 is estimated to cost $88,000.

DETAIL REPORT

"**Location and Length.**—The proposed reconstruction extends from Clover Street to the end of the brick pavement near the Barge Canal (Stas. 129+27 to 219+80.4), a distance of 1.71 miles, of which 0.12 mile is in the town of Brighton and 1.59 miles in the town of Pittsford. This proposed reconstruction covers the portion of Monroe Avenue which is at present in poor condition. The balance of Road 94 between Rochester and Pittsford is in very fair shape for traffic.

"**Previous Designs and Recommended Treatment.**—The portion of Road 94 covered by this contract has needed attention since 1918. In 1920 a survey was made and two alternate designs submitted. The recommended design of 1920 provided for widening the old 14′ macadam to 16′ with a slag-macadam extension and a new surface course of 2″ depth of Topeka Mix on a 1½″ average depth of binder evener course. Slag-macadam shoulders were provided on both sides of the pavement (3′ wide), giving a total width of hard surface of 22′. This design was estimated to cost $50,000. An alternate design was prepared but not recommended, using 6″ uniform depth of cement concrete 16′ wide at an estimated cost of $60,000.

"At the time these estimates were made (1920) the old macadam was firm but rough, and the additional 3½″ should have provided the additional strength needed to prevent deterioration under the growing volume and weight of traffic. During the last 3 years, however, the value of the old macadam as a base course has been greatly reduced, as the lack of the additional 3½″ proposed has permitted churning under heavy loads which would not have occurred had the pavement been strengthened at the proper time. This loss of effectiveness due to breaking of the bond makes it advisable to eliminate consideration of the use of the old macadam as a base for an asphaltic-concrete top, and makes it desirable to construct some kind of a rigid pavement. Considering limitation of funds, cement concrete is probably a reasonable solution for this contract.

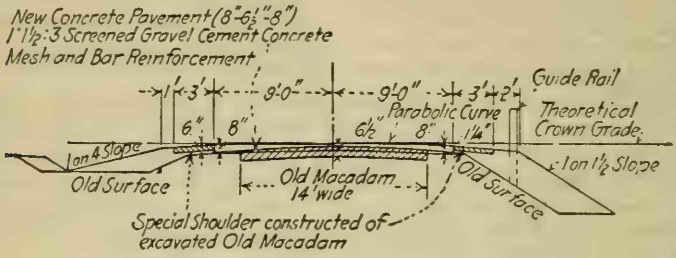
"The only way any practical value of the old macadam can be procured is to drop the new pavement into the old road and use the excavated macadam for shoulders close to the concrete. This has the double advantage of reducing fill and getting a firm solid shoulder at small cost. This is the general basis of the present design.

"It can readily be seen that the delay in reconstruction due to shortage of funds has greatly increased the cost of the necessary work.

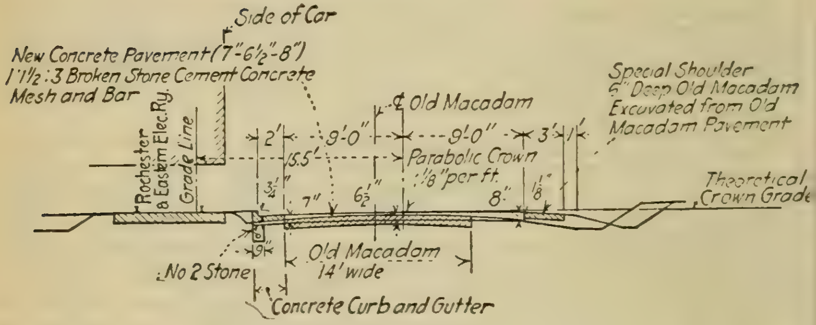
"**Recommended Section.**—The chief problem in the design is the matter of drainage along the car tracks, Stas. 129 to 184. The best method of treatment is Design 2, with the curb and catch-basin construction. If the curb is not used, J. E. Kelley has made the excellent suggestion of using a one-way crown away from the track, which will help in the matter of surface-water seepage under the left edge, but will not entirely eliminate this trouble. On account of this seepage and the poor character of the soil on the outer edge of the old shoulder, an edge depth of 8″ for Design 1 is recommended. The center gets some benefit from the old macadam and less seepage softening, and a 6½″ edge depth is recommended. For Design 2, an 8″ edge

depth is recommended where no gutter is used, and a 7″ edge depth where gutter is constructed. The center depth is the same as for Design 1. Excavated macadam is to be used for the new shoulder next to the concrete.

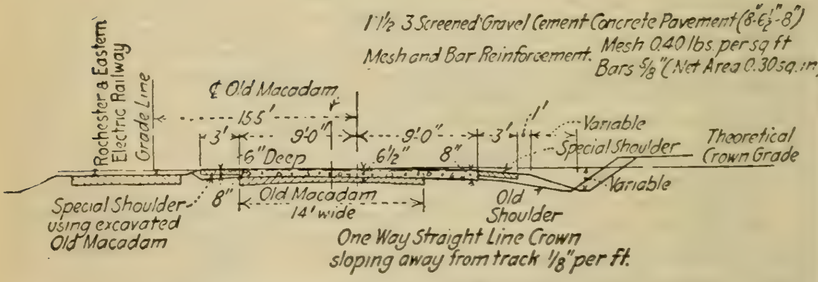
"**Culverts.**—The existing culverts on this road are the old-style vitrified-clay pipe and are, as a rule, in poor condition. New cast-iron pipe has been designed.



Alternate Design Sta. 129 to 184.



Recommended Design Sta. 184 to 219.



Recommended Design Sta. 129 to 184.

FIG. 182.—Recommended and alternate designs reconstruction road 94 (1923 design—estimated costs $88,000 and $78,000).

"There are two old masonry structures which should be pointed up, given new footing courses, and lengthened by the town of Pittsford.

"The Rochester & Eastern Electric Ry. should be required to provide the necessary outlet structures under their tracks to take care of the large flow at culvert locations, and to handle small ditch flow at intervals of not exceeding 300′.

"Alignment and Grade.—The alignment is excellent. The sharpest curve is 5°. No new right of way will be required.

"The grades are easy, 5 % maximum.

"The grade line as laid will provide enough excavated old macadam for the new proposed special stone shoulders. For the new earth shoulder widening both borrow and overhaul will be required.

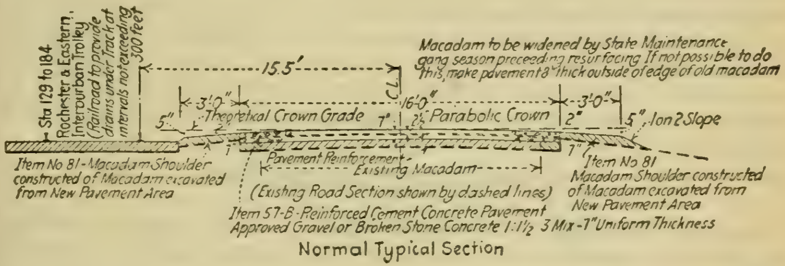
"Borrow.—Borrow can be obtained from the Barge Canal spoil banks within 2000′ of Sta. 219, or from the old tow path of the old Erie Canal west of Lock 32. The first source is the more feasible and has been used in computing overhaul.

"Materials.—Stone and sand must be imported, delivery (West Shore Ry., Pittsford) 1000′ from Sta. 220 of this contract.

"Water, Lake Ontario Water Company, hydrant at Sta. 136 and new proposed Long Meadow pipe line, Stas. 190 to 219.

"Cement, Pittsford delivery (West Shore Ry.).

(*Signed*)
Designer."



Recommended design reconstruction road 94 (1920 design estimated cost $50,000).

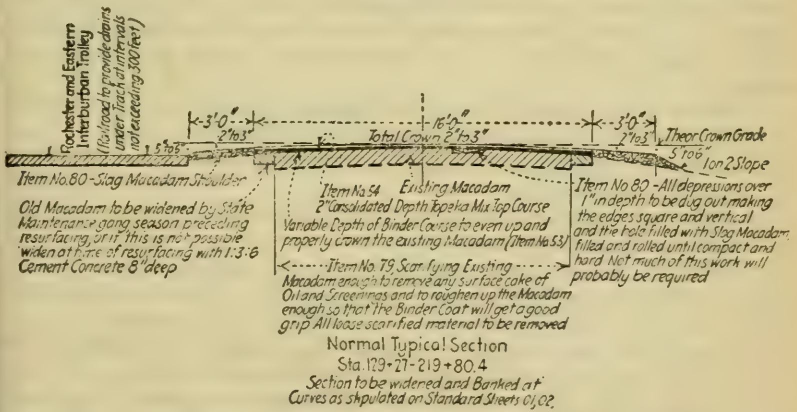


FIG. 183.—Alternate design in 1920. Estimated cost $60,000.

Note.—A comparison of figures 182 and 183 shows the effect of delay in reconstruction cost due to serious deterioration of old macadam.

Suitable Surfaces.—The suitability of surfaces has been thoroughly discussed in Chaps I and VI. The same conclusions hold, namely, that for Classes III and IV water-bound macadam oiled, or gravel well maintained by dragging and oiling, are satisfactory under all conditions. These surfaces are satisfactory on any steep grade occurring on improved road systems. For Class II traffic,

water-bound, penetration bituminous macadam, asphaltic concretes, cement concrete, or any standard block or small cube is satisfactory. The limitations of use on account of grade have been discussed (see pp. 425 and 101). Standard-sized paving brick, asphalt block, etc. are not so rational as the smaller units on a flexible base and they also increase the difficulties of shoulder work.

For Class I, any standard type of high-grade surface is suitable under limitations of local preference and final cost discussed in Chap. VI. At the present time, the most easily used type for Class I resurfacing is some type of asphaltic concrete, but on steep grades this is not very satisfactory and it is hoped that the brick or stone manufacturers will produce a satisfactory smaller unit-sized block for these conditions. On main roads it is desirable to use a surface which is not maintained by surface oiling, as the oiling process is disagreeable for traffic for a short period each season. On secondary roads, short-time annoyance of surface oiling is far outweighed by the reduced total cost of the macadam type, that is, very few communities can afford perfection of comfort on secondary highways.

RECONSTRUCTION DESIGN

General Principles of Design.—Each road is a special problem requiring a complete knowledge of the strength of the existing pavement and careful alternate estimates of different methods of treatment. There are an innumerable number of solutions which serve the purpose, provided the general basic principles are not violated. A few typical examples are given to illustrate common cases. Basic principles of reconstruction design are listed as follows:

1. Make all necessary alignment changes on the score of safety or reasonable maximum grades (see official report, p. 594).
2. Adequate pavement width is essential and should be provided at this stage of programs.
3. Retain the same general type of foundation unless existing pavement is practically worthless.
4. Strength design for either the macadam or rigid type is determined in the manner discussed in Chap. VI. High-type surface should never be used on a weak base. This is often done.
5. Suitability of surface depends on traffic demands. On heavy-traffic roads, avoid a surface which requires oiling.
6. Retain same type of surface where existing pavements are to be widened only.
7. Avoid use of so-called dual types unless unusual conditions, such as central car tracks, prevail.
8. Safe and solid shoulders are essential.
9. Avoid deep, dangerous ditches. Use storm-sewer systems if possible to eliminate dangerous ditches.

Utilization of Old Macadam or Gravel.—An old macadam pavement must never be scarified unless the loosened material is entirely removed and used for shoulder material on the side of the new surfacing. Scarified macadam never can be put back into a good hard lock as the mechanical bond of the larger stone fragments is broken

and they are completely separated by the screenings. Scarified macadam is nothing but a stone gravel which cannot have the stability of the interlock construction. Inequalities and shape of crown must be corrected by adding new material.

If an old macadam pavement is to be widened and used as a base for a high-type surface, the widening should be done by state maintenance forces a year before the resurfacing, in order to give it a chance to harden under traffic. If the widening and new high-grade surface must be constructed hurriedly, the most feasible solution is to use 1:3:6 concrete about 8″ deep for the foundation widening in place of macadam, although this method is not advised nor is it often necessary with reasonable forethought. If an old macadam is to be widened and recapped with macadam on Class II or Class III roads, all the work may be done the same season, although it is desirable to complete the widening well in advance of the new top and give it considerable traffic pounding to better the consolidation.

If an old macadam pavement must be strengthened before being recapped with a high-grade asphaltic concrete or block surface, the resurfacing additional thickness of macadam must be constructed a year ahead of the final resurfacing to give it a chance to harden under traffic. Asphaltic concretes or block surfaces must never be laid on new macadam which has not been pounded by traffic for at least 6 months.

All potholes must be dug out at least 3″ deep, the edges squared up, filled with 1¼ to 2½″ stone or slag, thoroughly rolled, filled with slag or stone screenings, and well compacted. Cold patch should not be used for work of this kind. Potholes must never be filled by varying the depth of the macadam of the overlying course.

The reinforcing middle course must not be laid until all potholes are completely repaired. This course must be fairly uniform in thickness; there should be no sudden variation of over 20% in finished depth.

The top course must be very uniform in thickness. Macadam top should have no sudden variation of more than 15%, and asphaltic-concrete surface mix no sudden variation of more than 10% in depth. These rules in regard to uniformity of depth are violated quite frequently and explain many unsatisfactory repair jobs.

For method of utilizing existing macadam where a new rigid-type pavement is to be used, see pages 583 and 585.

Case 1. Widening Existing Pavements.—This case is illustrated by Figs. 184 to 185, Road 5 near Rochester, N. Y., carrying 4000 to 5000 vehicles daily (10-hr. count in summer). This road is an asphaltic concrete (modified Topeka) on concrete base, Stas. 0 to 74, and an Amiesite top on macadam base, Stas. 74 to 130. The foundation soil is sand and gravel. It serves traffic well with the exception of width. Figure 184 shows the first design prepared, which violated all the basic principles of reconstruction design. It changed general type of foundation and used different types of surfacing. Figure 185 shows a new design which not only retains type but is cheaper in construction cost. Figure 185 is a satisfactory design for a case of this kind, except that the concrete base

should be thicker than shown (for recommended depths, see Table 86, p. 426). The object of the undercut concrete base connection is to prevent separation of additional base from original base; it gives a good grip contact.

Case 2. Recapping a Worn-out Rigid-base Pavement Having a Removable Top.—This case is very simple; it merely involves the removal of the old, worn-out surface and its replacement by any standard type of surface desired. The old rigid base is retained and repaired if necessary. New edging or stone shoulders bound with bitumen are provided. This case does not require illustration by typical sections.

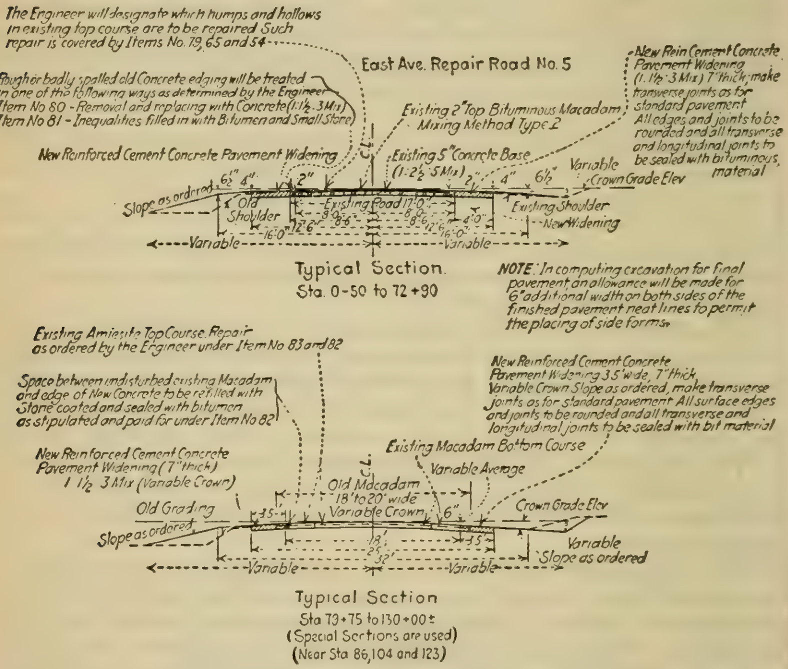


FIG. 184.—Design 1, Road 5, this design violates all principles of reconstruction.

Case 3. Recapping a Worn-out Monolithic Rigid Pavement of Ample Strength and Width.—Broken-down or weak areas of the old pavement are cut out and removed and the edges of the retained pavement squared up. The subgrade is undercut along the connecting edge similar to Fig. 186; new concrete base is laid and well tamped into the undercut. This concrete is protected from traffic and allowed to set 14 days before the new surface is placed. Two general types of surface can be used, asphaltic concretes, or any standard block or cube form of pavement.

If asphaltic concrete is used, the procedure is essentially as follows: Potholes in the old pavement over ½" deep, but not too

deep to weaken the base, are chiseled out to a square edge and filled with coarse-stone cold-patch material filled with coarse sand and thoroughly rolled. Small depressions, cracks, and crown irregularities are cleaned out and filled by varying the depth of regular binder course. For this purpose, an average depth of 1 to 1½″ compacted binder is generally sufficient. The final surfacing can be constructed of any desired mix of asphaltic concrete ranging in depth from 1½ to 2½″ as desired. For Class II or II*A* traffic, 1½″ modified Topeka makes a good surface; for Class I traffic,

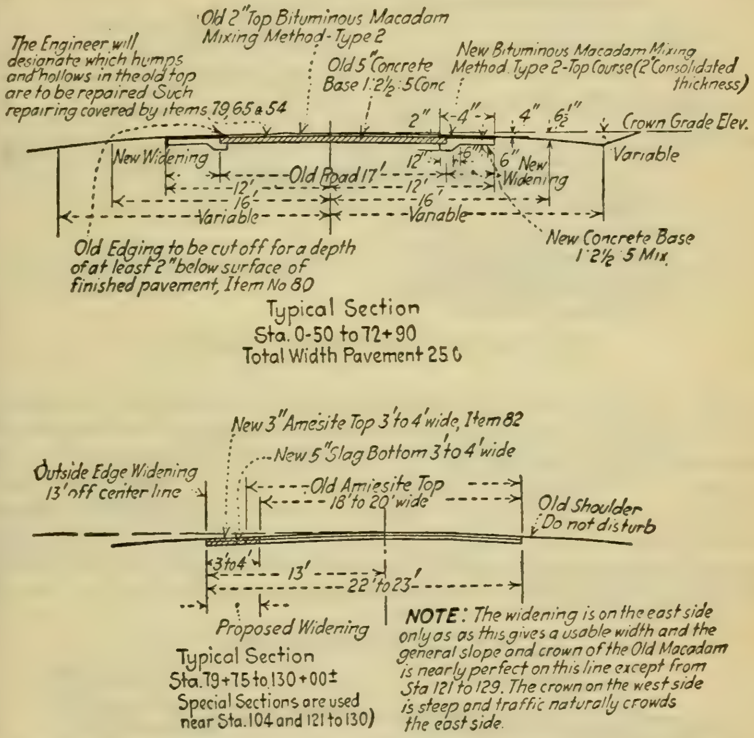


FIG. 185.—Design 2, Road 5, this design complies with basic design principles and is cheaper than design 1.

2″ of fine aggregate sheet asphalt makes a good surface. The thickness of the surface course must be uniform (see p. 587). Well-compacted bituminous macadam shoulders at least 4 to 6″ deep and 2′ wide should be constructed along the edge to prevent excessive edge wear of the high-class pavement. Safe width of grading shoulder and safe ditch section should be provided. This case is illustrated by Fig. 186.

If a standard block surface is used, the repair of the base for weak areas is the same as described. Pothole repair for depressions over ½″ deep consists of chiseling out to a square edge and filling

with 1:2:4 or 1:½:3 concrete which is protected and allowed to set for 14 days. Cracks, minor irregularities of crown and small depressions are cleaned out and removed by varying the depth of the cement-sand cushion on which the new surfacing is to be laid. An allowance of 1″ to 1½″ average depth of 1:4 cement-sand cushion is generally ample to meet this requirement. On this cement-sand cushion, the block surface is constructed in the same manner as for original construction. The edge of the pavement

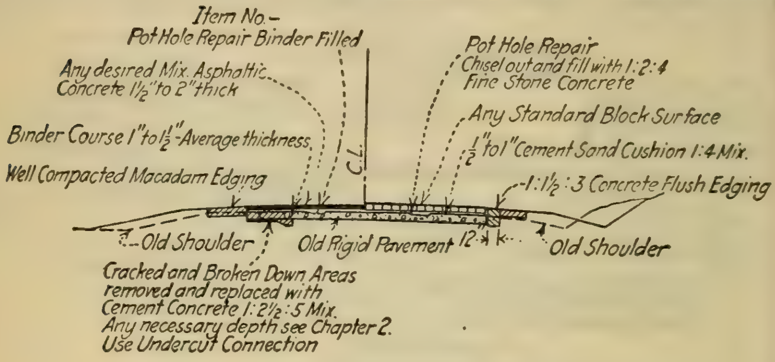


FIG. 186.—Typical design, Case 3.

should be protected by a simple concrete flush edging outside o which the stone shoulder, earth grading, and ditch section are th same as for the previous case. This case is illustrated by Fig. 186

Case 4. Change of Type on Class I Traffic Road. a. Wher Old Macadam Is of Ample Width.—Drop a new rigid pavemen below surface of old, rough macadam in order to get a uniform sup porting surface and in order to obtain cheaply the stone shoulde needed on each side of the new rigid pavement; that is, the ol

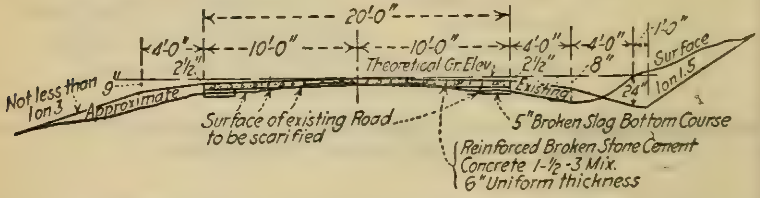


FIG. 187.—Case 4, example of poor design.

macadam top course is scarified and removed and used as a shoulde along the sides of the new pavement.

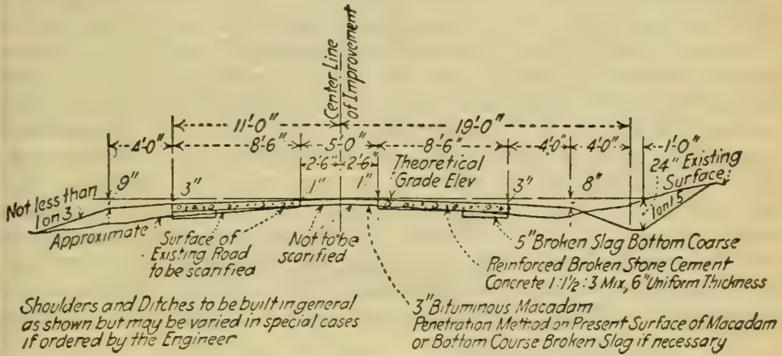
The new pavement should be of ample depth for macadam suppor conditions (see Chap. VI on Design, for the effect of macadam underlying support).

b. Where Old Macadam Is of Less Width Than New Pavement.— The same procedure applies in regard to scarifying, removing old top, and utilizing it for new shoulder. In designing depth, it is

good policy to increase edge depth over middle depth where the advantage of macadam support is lost. It is poor design to attempt to widen the macadam and then use uniform depth of new pavement (see also Chap. VI for relation of edge to center depth).

Figure 187 illustrates poor practice. Figure 182 illustrates good practice.

Case 5. Three-strip Dual Type of Construction, Class I Traffic (Not Recommended).—The general idea of this type of reconstruc-



Case 5. Dual type (poor practice).

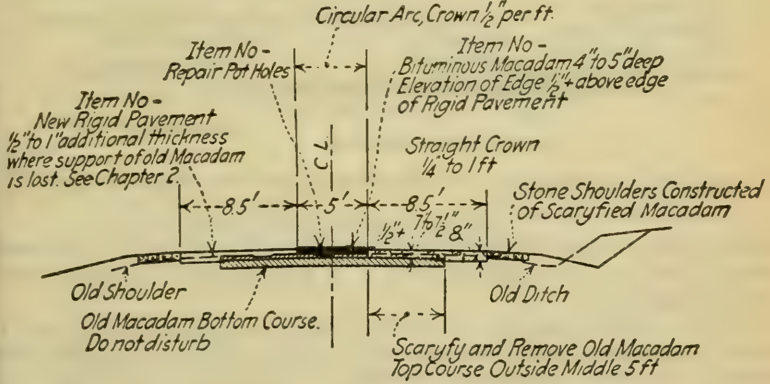


FIG. 188.—Case 5 (good practice).

tion is shown in Fig. 188. Mixed types are generally considered poor design, as they are expensive to maintain, although the dual type is quite popular with traffic, as it tends to separate the lines of travel.

The same principles of utilizing old macadam top course for shoulder material applies as in Case 4; the same principal of deepening the pavement along the edges where it loses macadam support applies as in Case 4. Case 5 is illustrated by Figs. 188 (poor practice) and 188*A* (good practice).

Case 6. Recapping Firm Rough Macadam.—Potholes in the surface over ½" deep are picked out for the full depth of the top course, and the edges squared up. The hole is filled with regular top stone or slag (1¼" to 2½" size), thoroughly rolled to a tight lock, filled with coarse sand or screenings, and hard rolled. The surface course is then laid in the usual manner, using any type desired. Water-bound or penetration bituminous macadam 3" consolidated depth can be used for Class III traffic. Penetration bituminous 3" deep is satisfactory for Class II traffic. Some form of asphaltic concrete, preferably of the coarse aggregate type averaging 2½ to 3" finished depth is satisfactory for Classes II or II*A*. Coarse-graded Amiesite is particularly adapted to such cases, as it adds materially to the structural strength of the old base. Under the heavier II*A* traffic, a 1" binder course with 1½ to 2" of modified Topeka is a good solution, provided steep grades are not encountered. The thickness of the top course must be uniform. On steep grades, the single-pour bituminous macadam or small cubical block surface is used. If a block or cube surface is used the minor surface irregularities of the old macadam remaining after the potholes have been repaired are eliminated by a varying depth of 1:4 cement-sand cushion; joints are filled with either bitumen or sand

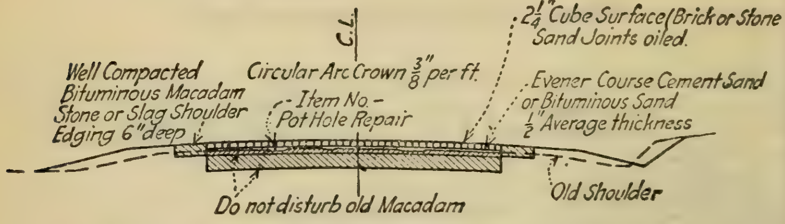


FIG. 189.—Recapping old firm macadam with cube surface.

with a light surface oiling. The new shoulders should be a good gravelly soil and the grading width of new shoulders and ditches must be safe.

Dont's.—In recapping an old, firm, rough macadam, do not scarify the old surface and add material (see p. 587). If the old surface is a smooth, slippery, flush-coat, bituminous macadam on which it is difficult to get a good grip for the surface coat, it can be either scarified and completely removed and used on the shoulder, or a 3½" depth of new top can be used which has considerable internal stability of its own, or a bituminous paint binder can be applied overlaid with an open mix binder about 1" deep and finished off with a Modified Topeka surface mix.

Don't attempt to widen an old macadam base the same year that it is recapped with a high-grade asphaltic-concrete or block surface for Class II*A* or Class I traffic. Widening for this class of work should be done the preceding year. Under Class II or Class III traffic with an ordinary macadam recapping, this restriction does not hold. If a quick widening is absolutely necessary for Class I or

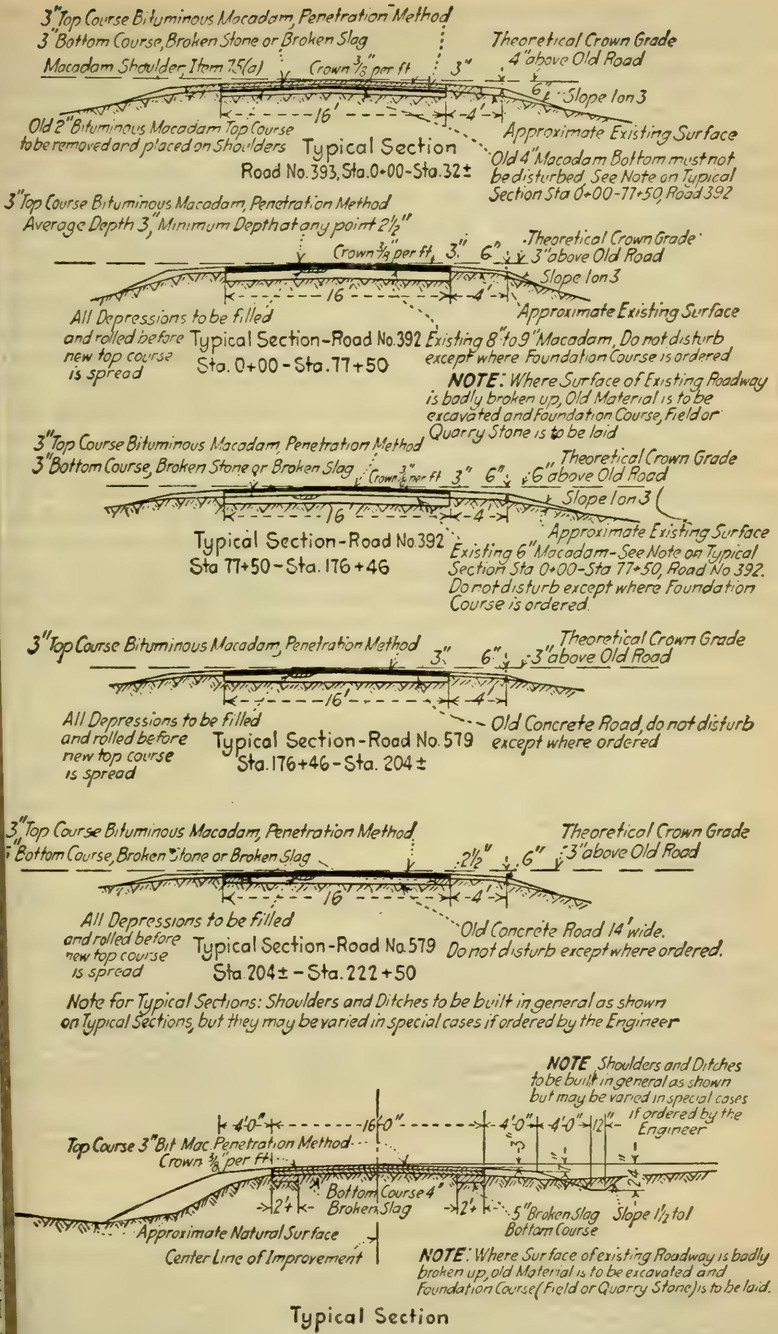


FIG. 190.—Case 7. Good typical example of widening, strength-
ing and recapping an old narrow weak macadam pavement.
ivision 4, New York State.

Class II*A* traffic, a depth of 8″ of 1:3:6 cement concrete for the additional foundation width is probably the best solution.

The final top course must be uniform in thickness (see p. 587).

Case 7. Reinforcing and Resurfacing an Old Weak Macadam, Traffic of Classes IIA, II, or III.—Actual conditions as to underlying soil and existing depth of macadam must be thoroughly investigated by test holes and records of spring blow-ups. The portions of the road which are entirely inadequate should be completely removed and rebuilt to the proper depth (see Chap. VI, p. 391). For this work, regular construction methods apply, utilizing any available type of subbase or foundation course. Where a middle reinforcing course of 3 to 5″ depth in conjunction with the new surface course will produce an adequate depth, the old road is left untouched. Potholes are repaired as in Case 6. These must be repaired before the reinforcing course is laid. The reinforcing course is essentially the same as ordinary macadam bottom, and ordinary construction methods and materials requirements apply. The top-course construction is the same as for new construction where water-bound or penetration macadam is used. If a high-grade asphaltic concrete or block surface is contemplated under Class II*A* traffic, it must not be laid the same season as the reinforcing course. Traffic must be permitted on the reinforcing course for at least 1 year. Under these conditions, and reinforcing course should be bound with screenings instead of sand and raveling prevented by applications of calcium chloride (Case 7 illustrated by Figs. 189 and 190).

TYPICAL REPORT ILLUSTRATING ADVANTAGE OF RECONSTRUCTION RELOCATIONS

Rochester, N. Y.
May 16, 192[illegible]

"Mr. ——————,
Division Engineer,
Rochester, N. Y.

"Dear Sir:

"Find attached detail report on the proposed relocation of Clover Stree[t] Road 294, Stas. 0 to 9 (canal crossing).

"We recommend a 16′ bituminous-macadam pavement on straigh[t] alignment with 5% maximum grade at an estimated cost of $9500. [I]f cement-concrete pavement is used the cost is estimated at $11,800.

"This relocation is justified on the score of safety alone, as it eliminate[s] two sharp curves, an 8% grade, and an old narrow, unsafe bridge. Th[e] reduction in motor operation cost on the new line probably warrants [a] construction expenditure of about $10,000, but this consideration need not b[e] given much weight for this particular project, although it furnishes addi[-]tional argument in favor of the work.

Sincerely yours,
Designer."

DETAIL REPORT

Clover Street Road 294 (Canal Crossing)

"**1. Location and Length.**—The proposed relocation extends from Monr[oe] Avenue Road 94 to Sta. 9+00 of Clover Street Road 294, a distance of 900 [ft.]

"**2. Traffic Classification.**—Road 294 is on the borderline between Class I[I] and Class III traffic. The 1920 census gives 550 vehicles in 12 hr. summ[er] travel and the 1922 census 400 vehicles in 12 hr. For purposes of estimati[ng] the economic value of the proposed improvement an allowance of 8[00] vehicles daily will be made.

"3. **Grades and Alignment.**—The proposed relocation materially improves the grade and alignment. The existing alignment has two sharp curves, one of 75′ radius and one of 200′ radius. The existing grades are steep, and an 8% bridge approach grade is the maximum. The proposed alignment is straight with a 5% maximum rate of grade. The distance on

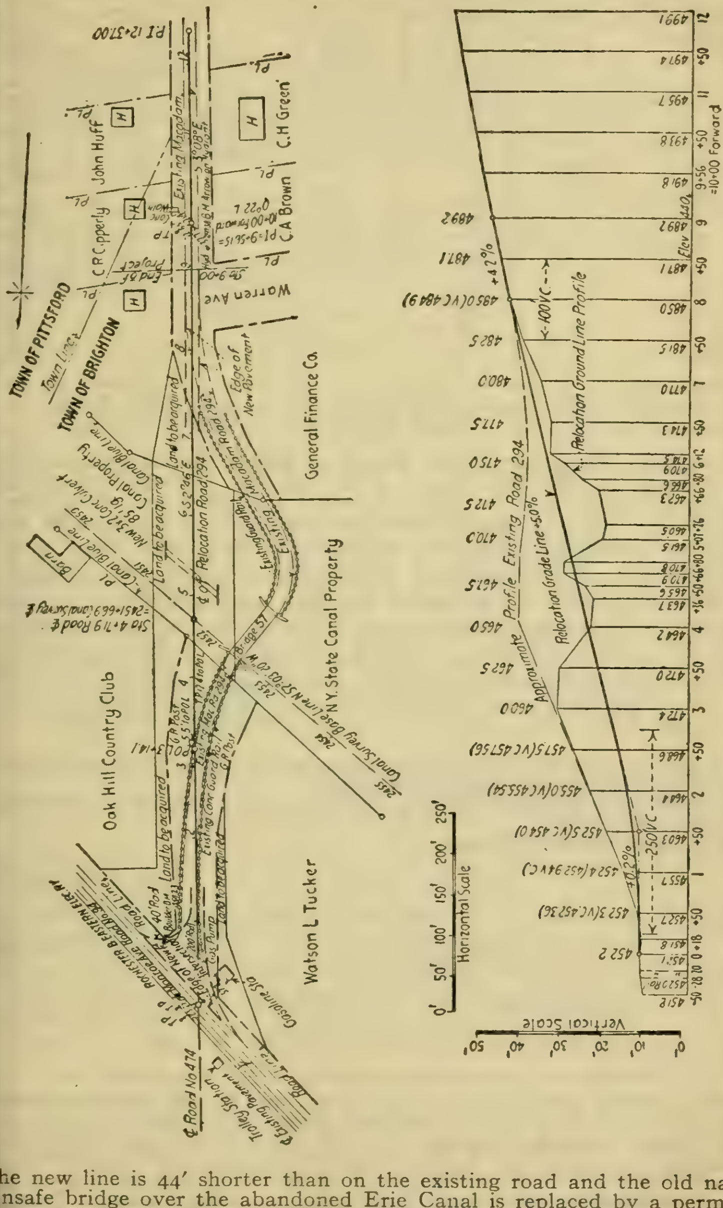


FIG. 191.—Plan and profile to accompany official report illustrating the value of the Clover Street relocation.

the new line is 44′ shorter than on the existing road and the old narrow, unsafe bridge over the abandoned Erie Canal is replaced by a permanent fill with culvert drainage. The cost of the necessary grading on the new location is estimated at \$4000. The economic benefit of this grading is estimated at \$10,000. (see following tabulation based on curve 1, Fig. 2, p. 13).

TABULATION OF CAPITALIZED MOTOR OPERATION COSTS
(Old and new locations, Stas. 0 to 12 + 00)

Rate of grade, per cent	Estimated capitalized cost, motor operation, 100 vehicles daily per foot of distance	Old profile		New profile	
		Distance feet	Amount	Distance feet	Amount
1 or less	$ 9.10	80	$ 728	50	$ 455
2.0	9.15	320	2,928		
2.6	9.21			200	1,842
3.0	9.25	100	925		
3.4	9.31			100	931
3.9	9.37			100	937
4.0	9.40	80	752		
4.2	9.46	300	2,838	156	1,475
5.0	9.70			550	5,335
8.0	12.50	320	4,000		
Totals.........		1,200	$12,171	1,156	$10,975

Net capitalized advantage of new line per 100 vehicles daily, $1200.
Net advantage 800 vehicles daily, $9600, say, $10,000.

"4. **Suitable Pavement Types (Based on Traffic Classification).**—Th road is Class II traffic (see Sec. 2 of this report). For this volume ar character of traffic either bituminous macadam or cement concrete will ser satisfactorily. For the special conditions prevailing, it is probable th bituminous macadam is the more rational type to choose, based on tl following facts. This relocation is a short piece of Road 294, which is bituminous-macadam construction; it connects at the north end (Sta. with Road 474, which is bituminous macadam, and with Road 94, whi is bituminous macadam to the west and will be reinforced cement concre to the east. This relocation will have some deep fills which will pro ably settle for 2 or 3 years after construction, which is not a favorable co dition for rigid-pavement construction. The existing macadam of the o road can be excavated and reused for subbase course of the new macada construction which gives a distinct economic advantage to the use of th type.

"For record purposes comparative estimates have been prepared for bo bituminous macadam and cement concrete.

"5. **Soils.**—The subgrade soil is a medium clay comparatively free fro ground-water seepage.

"6. **Uniform Strength Design.**

Station to station	Soil	Grading conditions	Total pavement depths[1]	
			Macadam	Concret
0–2	Medium clay	Cut and shallow fills	16	7
2–7	Medium clay	Fills over 3″ deep	11	7
7–9	Medium clay	Cut and shallow fills	16	7

[1] These depths are based on Table 74 (p. 391) for the macadam desi and on the minimum allowable depth of concrete pavements (p. 453).

"As further evidence of proper allowable depth of macadam on this ro the existing macadam (10″ deep) is in perfect shape on the high-fill Stas. to 5 after 10 years' use. At no point on Road 294 has there been a evidence of weakness where the old macadam is 16″ deep in cuts. This c road carries a regular milk-collecting truck route and this evidence extendi over 10 years seems to strengthen the conclusions expressed by Table (p. 391).

"For the macadam construction a 3″ depth of top course is recommended; 4″ depth of new stone or slag for middle course; and from 4 to 9″ of reused ld macadam for the foundation course.

"7. **Materials Required** (**Pavement Estimate**).—There are 1900 sq. yd. f pavement on this job. The macadam type of pavement will require: 20 cu. yd. foundation course (4 to 9″ thick); 200 cu. yd. middle course 4″ thick); 160 cu. yd. top course (3″ thick); and 4300 gal. of bituminous inder.

"The concrete type of pavement will require: 360 cu. yd. concrete 1 : 1½ : 3 nix (6⅔″ thick); 700 bbl. cement; 17,200 sq. ft. mesh reinforcement (40 lb. er 100 sq. ft.); 7000 lb. bar reinforcement; 400 lin. ft. expansion joints.

"8. **Materials Available.**—The only local material available is the existing nacadam, Sta. 0 to 9, which can be excavated and reused for foundation ourse macadam construction; 350 cu. yd. of this old macadam are available or reuse.

"All other materials must be imported: cement (Pittsford delivery); stone Pittsford delivery or truck from Rochester); sand (Pittsford delivery or truck om Rochester); bitumen (Pittsford delivery or Tarvia from Brighton); water hydrant supply Stas. 0 and 9, Lake Ontario Water Company).

"9. **Comparative Estimates** (See Table 97, p. 520).

Type of pavement	Average thickness, inches	Cost per square yard of pavement: Estimate construction cost	Yearly interest	Yearly maintenance	Yearly renewal	Total yearly charge
Bituminous macadam......	13	$2.10	$0.105	$0.035	$0.11	$0.25
Cement concrete...........	7	3.20	0.160	0.010	0.12	0.29

"Grading, culverts, and incidentals are estimated at approximately $4900.

"The total cost, including all items with an allowance of approximately 800 for engineering, inspection, and contingency, is as follows:

Bituminous macadam........................... $ 9,500
Cement concrete.................................. 11,809

"10. **Maximum Allowable Expenditure and Final Recommendations.**—ny necessary expenditure is allowable on this project on the score of safety s outlined in the first paragraph of the report. The economic advantage f the new location due to better grades and shorter distance probably arrants a construction expenditure of about $10,900 to $11,000 (see Sec. 3 f this report). The new pavement does not reduce motor operation costs ppreciably, as the present pavement is equivalent to a first-class asphaltic oncrete surface as far as operation is concerned. The total economic value f the proposed work does not probably exceed $11,000 to $12,000.

Either cement concrete or bituminous macadam could be constructed ithout loss to the community, but the selection of bituminous macadam eems a better business investment in this particular case, as discussed in ec. 4 of this report.

(*Signed*)
Designer."

TYPICAL REPORT ILLUSTRATING THE EFFECT OF UTILIZATI OF OLD MACADAM ON RECONSTRUCTION COSTS

Rochester, N. Y.,
Apr. 10, 1923.

"Mr. ——————,
Division Engineer,
Rochester, N. Y.

"Dear Sir:

"Find below summarized design report on the reconstruction of Road State Route 30, Class II*A* traffic, from St as.89 to 239 + 35, a distance of 2 miles.

"We recommend an entirely new cement-concrete pavement 7″ aver depth, Stas. 89 to 132. From Stas. 132 to 239 we recommend that the macadam (at present ranging in depth from 8 to 11″ as determined by test holes) be retained as a base course, widened to 18′ with gravel fo dation course, the thickness of the old road increased by the addition of a slag water-bound middle course, which is to be used by traffic at leas months, and then capped with 3″ of some type of asphalt concrete p erably Amiesite or Topeka. This design is estimated to cost $134,c If cement concrete is used for the entire distance, the estimated cos $146,000. These two designs are practically equal from the standpoint maintenance and motor operation costs.

"An alignment change is made between Stas. 109 and 114; this change alignment is amply justified on the score of safety regardless of the increa cost. It increases the cost over following the old road about $11,000, bu probably cheapens the cost of motor operation enough to warrant a c struction expenditure of at least $6000, even if the increased safety is gi no weight in the decision.

Sincerely yours
Designer.

Actual Procedure.—This road was constructed of concrete for the en length on account of impracticability of using both cement concrete a bituminous hot mix equipment on such a short job.

CHAPTER IX

HE PROTECTION AND ELIMINATION OF RAILROAD GRADE CROSSINGS

Introduction.—Railroad grade crossings are a source of danger nd delay to highway traffic. Danger is present in all cases and is ie main factor to be considered. Delay, with resultant congestion, ecomes important on city streets or on heavily traveled rural roads hich are frequently blocked by long, slow freight trains. Danger an be materially reduced by means of various kinds of warning nd protective devices or entire safety secured by grade separations r highway relocations. Delay can only be corrected by grade eparations or relocations.

It is well recognized that the railroads and community at large re obligated to provide adequate safeguards at these crossings to rotect reasonably careful drivers. It is also quite well established hat large expenditures for the complete protection of reckless road sers are rarely justified, as such individuals are a positive menace o highway traffic and their death is a gain rather than a loss to ie community. This general premise results in the use of warning igns and signals for the great majority of the crossings and the se of eliminations on the more heavily traveled highways where elay, congestion, or unusual physical conditions make such contruction desirable for general community benefit.

It should be borne in mind however that while subway or overhead rossings eliminate danger of collision between trains and highway ehicles they introduce other sources of highway accident due to grades, urved alignment etc. That is unless such eliminations are well esigned they are often the source of accidents in themselves which did ot occur before the eliminations were constructed. (*See pages* 632, 4 *and* 646.)

Cost and Relative Value of Different Kinds of Protection.—dequate protection for careful highway users can be accomplished ith comparatively small expenditures, which are well within he means of most communities, by the intelligent use of different inds of warning signals and watchmen. The effectiveness of uch a program, however, depends on recognition of the limitations f the different kinds of warning devices and the selection of the est type or combination of methods which will meet the special onditions at each crossing. The advantages and limitations of he different methods of grade-crossing protection are discussed nder each type of signal. Complete protection and the prevention f delay by means of grade separations are costly matters, which ven the richest communities find difficulty in financing for any arge percentage of crossings. The following table indicates in

a general way the cost of different types of protection on rural higl ways for western New York conditions in 1925.

TABLE 111.—TABLE COSTS OF DIFFERENT TYPES OF PROTECTIO

Item	Approximate cost of installation	Yearly maintenance and operation	Yearly renewal	Total yearly cost interest 5%, maintenance and renewal
Approach warning signs...	$10	....	$ 2	$ 3
Pavement markings.....	....	....	15	15
Railroad signs..........	30	$ 3	5	10
Automatic signals, steam railway..............	1000–2000[a]	100	150	350[a]
	3000–6000[b]	200	300	700–100c
Automatic signals, electric railways..........	2500	20	200	350
Automatic signals plus 8-hr. flagman..........	....	....	....	1400
Flagmen (24 hr.)........	100	3100	....	3100
Hand gates.............	400	3200	100	3300
Electric gates with tower	2000	3500	200	3700
Grade-separation eliminations..............	80,000–200,000 100,000 average	200±	1300±	6500±

[a]Single and double track. Usual conditions.
[b]Four tracks.

The following table, based on accident data in Division 4, weste New York, for a period of 10 years gives some basis for judgmer as to the relative effectiveness of signal and watchman protectic (see Table No. 112).

TABLE 112

Method of protection	Relative number of accidents for uniform density of traffic for different methods. Corrected for traffic volume to make directly comparable with each other	Reduction in danger accomplished over unprotected conditions, %	Remarks
Unprotected or poorly protected crossings.....	10	..	Good data
Plain semiphore or banjo semiphore type of automatic signal...........	6	40	Meager data
Automatic wigwag oscillating-arm signal with bell attachment.......	3	70	Fair data
24-hr. watchmen or gates	2	80	Good data
Stop orders on electric interurban cars........	0.5	95	Good data

NOTE.—Automatic intermittent flash signals have not been in use lon enough for the accident records to be of much value. They are apparentl about comparable with the wigwag signal in effectiveness, but are not y as well understood by drivers as the swinging disc. This difficulty will t rapidly overcome with a little longer use. Where flash signals face directl into a low strong sun they are ineffective while this condition prevails.

A very conservative estimate of the relative value of these iethods of protection assumes that automatic signals reduce danger rom 40 to 60%; watchmen and gates from 50 to 80%; and well-esigned eliminations 100% plus the added advantage of the free assage at all times. It can be readily seen that the greatest reduc-ion in danger for the expenditure of limited funds can be obtained y the use of automatic signals in conjunction with well-built pproaches, warning signs, and pavement markings for the ordi-ary rural highway crossing. It can also be seen that where flag-ien and gates are needed on account of heavy traffic in conjunction ith railroad switching and shifting, which cannot be adequately erved by automatic signals, grade-separation eliminations are a ood business investment, provided the topography permits their rection for a reasonable first cost and the element of traffic delay dds to their value. Figure 192 shows cost and economic limit of ifferent methods of protection for different traffic densities in estern New York (page 602).

A common-sense solution which has been widely adopted is to ect automatic signals supplemented by watchmen where needed t all crossings on important roads and to proceed with a restricted rogram of elimination construction as the funds become available.

Financing.—The percentage of yearly highway funds that can e properly used for crossing protection should have some relation crossing danger as compared with the other sources of highway anger. The division of cost between the railroads and the com-unity and the method of taxation for public funds should have me relation to the benefit derived from such protection.

While the relation of railroad-crossing accidents to other highway ccidents will vary widely for different localities, available statistics ven in Chap. I (p. 34) indicate that, as a rule, grade crossings e responsible for from 6 to 10% of all highway accidents. Taking ie country as a whole, they are responsible for two deaths per year r 100,000 population. On the state highway system in western ew York, involving 207 grade crossings and an average highway affic of 800 vehicles daily, there have been approximately 190 rious accidents in 10 years, or an average of about 0.1 serious ccident per crossing per year. From the standpoint of damage aims, assuming all accidents, whether due to carelessness or not, ie average money damage would not exceed \$300,000 total, or 500 per crossing per year average for this territory, and probably d not actually exceed \$1000 per crossing. This indicates, in a neral way, that there is very little basis for using a large per-ntage of highway funds for crossing protection; that 10% would an extreme maximum; that 5% would be a large percentage; and at 2 to 3% is generally a more rational figure, considering that is phase of highway construction adds little to the economic value the system. The railroads are generally willing to spend some-hat more than their claim accounts for their share of such work.

It is quite generally recognized that, from a practical standpoint, is desirable to collect the necessary funds from both railroads d the local communities with some state aid. Whatever the ilroad pays is, of course, finally collected from the community

(text continued on page 603.)

Recommended Methods of Protection

1. Where crossings are located between stations and trains ar travelling at normal speed and no objectionable delay occurs w recommend good type automatic signals.

2. Where crossings are near station stops or yard switching c medium traffic highway we recommend automatic signals suppl mented by part or full time flagmen.

3. Heavy traffic rail and highway with congestion and dela requires eliminations.

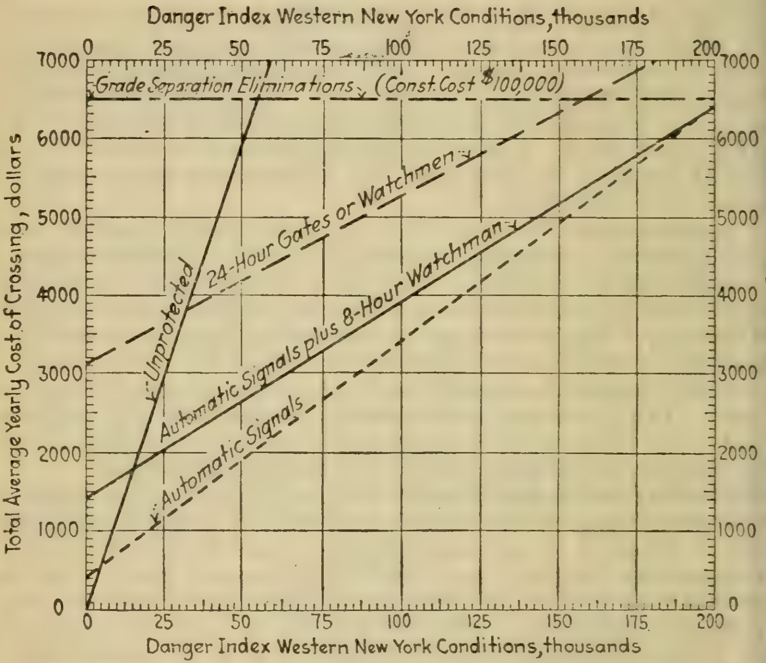


Fig. 192.—Diagram of probable total average yearly cost of cro ings for different volumes of traffic protected by different metho

Note: Total cost for each method of protection includes cost protection plus probable accident damage figured at $15,000 for ea serious individual injury. Diagram based on 10 year accident da on 200 crossings considering different volumes of highway and ra road traffic, visibility and physical condition of approaches.

Economic Limits for Different Methods of Protection

No protection—maximum limit— danger index 4000

Good automatic signals { min. limit—danger index 4000; max. limit—danger index 200,000

Signals + part time watchman { min limit—danger index 15,00; max. limit—danger index 200,(

24 hour watchmen or gates { min. limit—danger index 30,000; max. limit—danger index 160,000

Grade separation elim.—Min. limit danger index 40,000 to 100,(depending on const. cost.

From a practical standpoint the minimum limits are genera reduced by from 20 % to 50 % below these figures as crossing prot tion cannot be considered entirely, from a business point of view t the railroads should not assume the added cost over and above t

(continued at bottom of page 603.)

rough freights and rail charges of all kinds and beomes a general mmunity charge. If the amount paid by the railroad for these otective measures does not exceed their yearly damage-claim lls for unprotected conditions, their operation charge is not creased and the general public pays no special extra amount for ch protection. If the amount exceeds the damage-claim account, eventually becomes a general community charge. The direct x for public funds can be collected as a general tax or as a special hicle tax.

The railroads are benefited by protective measures in proportion the reduction of their damage-claim amounts. The highway ser is directly benefited by added safety of travel to him personally. he community at large derives only a small economic benefit from ch work unless it results in the elimination of delay on heavily aveled roads. It is a well-established principle that both rail-ads and the public should cooperate in the cost and operation of otective measures to the extent to which they are directly nefited and, while the principle is rarely adhered to exactly, is desirable to hold as closely to it as practicable. This indicates, a general way, that public funds should be raised by vehicle xation for this class of work, but should probably not usually ceed 5% of the total highway funds, and that the railroad funds ould probably not greatly exceed the damage-claim accounts.

Following the general principles of highway finance outlined in hap. 1 (p. 19), all expenditures for temporary signals, watchmen, c., should be paid from current yearly funds, while the more rmanent elimination construction may well be financed by 40-ar serial bonds.

Sample Report for a Specific General Case.—To illustrate the actical application of the foregoing discussion, conditions in ivision 4, western New York state highway system will be cited. he figures given are approximate only, but are sufficiently accurate warrant general conclusions for quite typical conditions.

923 Basic Data, Division 4, New York State, Railroad-crossing Program

ea	4,500 sq. miles
pulation	550,000
sessed valuation	$600,000,000
otor registration	100,000
tal road mileage (rural)	6,700
ate system mileage (proposed)	1,350 ±

Notes for Fig. 192 continued from page 602

onomic limit for the method of protection ordered by state or tional governments.

obable number of serious accidents per year

= danger index ÷ constant "P"

alues of constant P

P = 125,000 unprotected crossings

P = 500,000 wigwag or flash signals

P = 700,000 24 hour watchmen and gates

Note: For explanation of danger index see text of report, page 3.

Complied by
W. G. Harger, 1925
Grade Crossing Eng.

Average daily volume of highway traffic per mile of road	900
Percentage of total vehicle miles carried by state system	40% ±
Replacement value of finally complete state system, pavements, and bridges	$60,000,000 ±
Estimate yearly tax budget on completion of system, including maintenance, renewal, and construction-bond charges (pavements and bridges)	$4,000,000 ±
Total number of railroad crossings on state system (steam and electric)	251
Number of grade separations existing	44
Number of grade crossings well protected	57
Number of grade crossings poor or no protection	150
Number of miles of state road per crossing	5.4
Total average number of trains per day passing all grade crossings	6,000 ±
Total average number of highway vehicles per day passing all crossings	180,000 ±
Total danger index[1] (average daily potential risk) at grade crossings	4,000,000
Number of serious injuries per year (10-year average)	20 ±
Estimated damage, including personal-injury claims and minor accident damages	$250,000 per year
Serious injuries per 100,000 population per year	3.6
Daily danger index for single crossings representing probability of one serious accident per year (based on 10-year period, fairly good data):	
a. Unprotected or poorly protected crossings	150,000
b. Well-protected (watchmen or signals)	700,000
c. Stop orders, electric cars	No accidents occurred
d. Average all grade crossings in division	200,000

"The following data has been kept for a short time and on only a f signals, and must be used with caution:

e. Wigwag automatic signals	500,000
f. Banjo semiphore signals	250,000

"This indicates that signals and watchmen decrease danger from 50 to 7 over unprotected conditions and that stop orders on electric interurbans a effective in reducing danger. It also shows that, to be most effective, automatic signal should be of the oscillating or intermittent-flash type catch the eye readliy. *During* 1926, *grade-crossing accidents were only* 70 *of the* 1924–1925 *rates, due to the installation of* 37 *automatic signals in* 19 *and* 1926 *at the most dangerous unprotected crossings.*

"The local engineers recommended the following program for this distr as a reasonable solution, for 1923 conditions considering the conditio tabulated and the general principles of protection and financing previous outlined."

"Summarized Conclusions and Recommendations, Division 4.—It is n likely that it will be possible to obtain more than $100,000 to $150,000 p year for the state's and counties' share of work to reduce danger at gra crossings on the state road system in this division. After a careful study conditions in the division and discussions with county officials and automob owners we recommend the following program as being an effective way reduce danger with the funds at our disposal.

"1. The immediate installation of a uniform type of automatic audil and visible signal, preferably of the flash type (supplemented by watchm in the villages), at all unprotected crossings on steam railroads, and eith signals or stop orders on electric interurban roads. This work will co about $200,000 and should be completed in 1925–1926. This work can expedited by a modification in the railroad law to permit state cooperati in the cost of installation of such signals at state road crossings. It is certa that this work will result in more total reduction in danger to careful moto ists than any other method of expending the first $200,000. This part the program also includes bringing the physical highway conditions at t crossing and on the approaches up to the requirements of the Standa Specifications for grade crossings given on page 609.

"2. A 10-year program for the elimination of about 50 of the most dange ous grade crossings in the division estimated to cost $5,000,000 financed l 40-year serial bonds. The yearly budget for their retirement to be financ

[1] Note.—For derivation of danger index see page 623.

›y motor-vehicle taxation for the state and county share of cost (50%) and ailroad funds for the railroad share (50%). The state and county yearly ›udget for this work in this division will amount to about $125,000 yearly.

"3. The retention of signal protection at the relatively unimportant rossings until future necessity requires their elimination at an estimated ost of about $15,000,000.

"NOTE.—Existing eliminations, watchmen, signals, etc., have already liminated at least 40% of the danger on the state highways in this division steam and electric railroads).

"It is estimated that the remaining existing danger in the division at rade crossings will be reduced at least 50% for careful drivers by the expeniture of the first $200,000 for signals and that at least 90% of danger over he division as a whole will be eliminated on the completion of the 50 most mportant grade-separation projects with the balance of the crossings rotected by automatic signals or watchmen.

(*Signed*)
W. G. Harger.
Grade Crossing Engineer."

Sample Report for a Specific Individual Crossing.—In order to nake a reasonable analysis and arrive at any rational conclusion in egard to the best method of protection for any specific case conidering existing danger and funds available, it is necessary to conider probability of danger (see p. 623), probable yearly damage laims (see p. 602), and the relative effectiveness and cost of differnt methods of protection (see p. 602). A sample report follows lustrating the practical application of the data referred to.

"REPORT ON CROSSING 8, DIVISION 4, NEW YORK STATE HIGHWAY DEPARTMENT

ounty of Monroe, Division 4
ighway 62, P. S. Case
ame of crossing, West Henrietta Road
ame of highway, West Henrietta-Rochester
ame of railroad, Lehigh Valley
ranch, Rochester to Rochester Junction
own of Henrietta
umber of tracks, 1
ype of ballast, Gravel
eight of rail, 85 lb.
lignment of railroad, tangent
pproximate railroad grade, level
ny contemplated railroad improvement, none
umber of passenger trains daily, 12
peed of passenger trains, 40 m.p.h.
umber of freight trains, 4
peed of freights, 20 m.p.h.
rotection at crossing, none
ngle between center-line road and track, 58°
ighway pavement, bituminous macadam 16′ wide.
avement between rails, bituminous macadam 20′ wide
ighway approach grades, 1.22% north, 1.5% south
-hr. highway traffic count (August), 2,500
stimated average daily 24 hr. (year round), 2,200
isibility of approaching trains:
Poor in two directions
Good in two directions
ccident record, four accidents in 10 years, resulting in four deaths and two serious injuries.
robable yearly damage claims, average, $9,000 ±
ost feasible type of elimination, overhead highway.
stimated cost of elimination, $110,000
ost feasible method of temporary protection, automatic signals

"**Recommendations.**—We recommend the immediate installation of automatic signals at this crossing and its elimination as soon as funds become

available. We recommend that the pavement between the tracks be widened to 30′ and that the approach pavement be widened to 24′. While an elimination is undoubtedly justified, funds are not at present available and the signals will pay for themselves in a very short time and reduce danger at least 60%. These recommendations are based on the following data:

"**Danger Index.**

"Highway traffic factor	2,200
Visibility factor	1.2
Approach factor	1.0
Train factor	15

"Danger index in 1923 = 2,200 × 15 × 1.2 = 39,600, say, 40,000
Estimated index 10-year period 48,000, allowing for increase in volume.

"Probability of accident over next 10-year period for different methods of protection.

Unprotected $\frac{48{,}000}{125{,}000}$ = 0.4 serious accidents per year.

Automatic signals $\frac{48{,}000}{500{,}000}$ = 0.1 serious accidents per year.

24-hr. watchmen $\frac{48{,}000}{700{,}000}$ = 0.07 serious accidents per year.

Elimination = no accidents.

"Probability of yearly claim bill for different methods of protection, allowing $15,000 per serious injury.

Unprotected	$6000
Automatic signals	1500
24-hr. watchmen	1000
Elimination	None
The yearly cost of automatic signals is about	$ 400 ±
Watchmen	3000 ±
Elimination	6500 ±

"The use of signals will probably reduce danger about 70% and result in a net saving at this crossing of about $4000 per year. Watchmen will result in a net saving of about $2000 per year. Elimination will cost about the same as at present, but eliminates danger and delay. This crossing is number 11 in order of importance in Division 4 for elimination construction, and is number 2 in order of importance of the Lehigh Valley crossings.

(*Signed*)
Grade Crossing Engineer."

Causes of Accidents and Protective Measures.—A large percentage of the accidents, probably at least 50%, are caused by reckless driving, and no system of signs or signals will entirely eliminate such injuries (see Accident Causes, Chap. I, p. 33).

Accidents not directly attributable to recklessness are usually due to the following conditions and can be remedied at a small cost.

1. Motorists do not realize that they are approaching a crossing. This danger is reduced by proper approach warning signs (Fig. 196), pavement markings (Fig. 198), and standard crossing signs (Fig. 199).

2. Motorists do not realize that trains are approaching the crossing. This danger is reduced by automatic signals or watchmen and gates (Figs. 200 to 202). As a considerable percentage (15 to 20%) of collisions are due to automobiles running into the sides of freights trains at night, during rain or snow storms, it is necessary that signals or gates be placed on both sides of the tracks at the crossing. Accident records show the undesirability of central obstructions of all kinds on narrow rural highways, which makes it

desirable to locate the signal standards outside of the pavement area (see Fig. 193). In a similar manner gates should be located far enough back from rails to permit a standing automobile between gates and track in case a car gets caught inside of the lowered gates.

View of approaching trains can often be materially bettered by cutting trees, moving buildings and any other obstruction to view along the tracks. For a discussion of visibility see page 624.

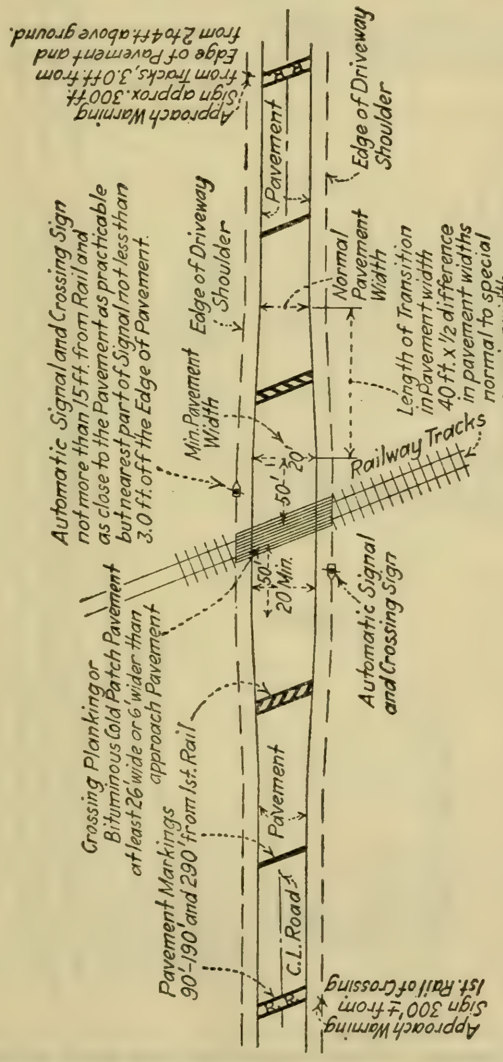


FIG. 193.—Typical rural highway grade crossing layout for signs, signals and pavement and planking widths.

3. Motorists get one wheel of their car off the pavement proper and hit the railroad track, which results in stalling the engine or diverting the machine from the roadway along the track or into a ditch. This can be remedied by making the planking or pavement between the rails wider than the approach pavement (see Fig. 195).

4. Cars often stall on the tracks due to inexperience and nervousness of drivers in applying power over a rough crossing. The remedy for this condition is to make the crossing smooth and keep the rails in the same plane, so that cars will be kept in motion with

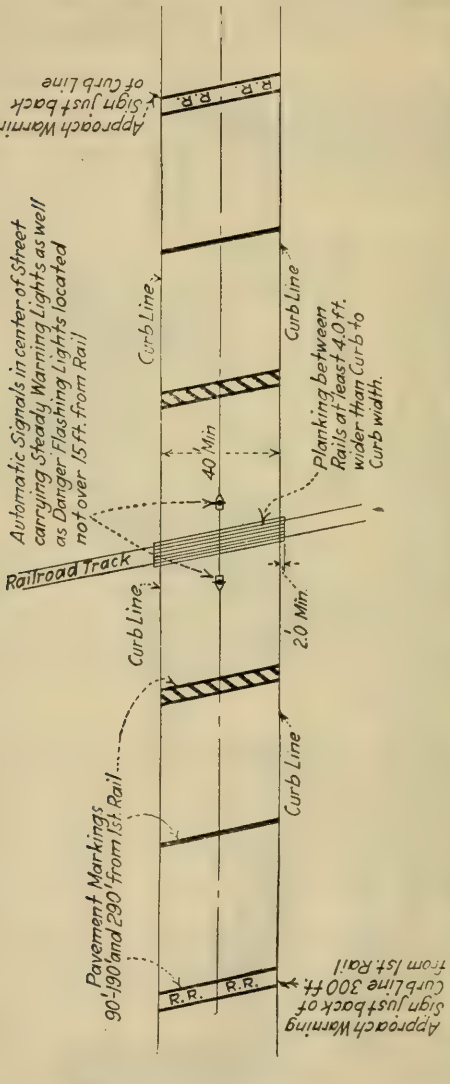


FIG. 194.—Typical village or city street grade crossing layout for signs and signals. *Note:* Central location of signals not permissible for widths of less than 40 ft. curb to curb. For less width use side location as shown in Fig. 193 for rural layouts.

a minimum of power. Where more than one track is crossed, the rails should all be at the same elevation on railroad tangents, and on curves the railroad track superelevation work on adjacent track should be sufficiently close to the same plane to eliminate noticeable bumps.

5. Trains are derailed by collisions with motor vehicles resulting n injury to passengers or train hands. This type of accident ccounts for 1% of injury and death at crossings according to nterstate Commerce Commission 1925 Statistics.

The Hoover National Committee on Highway Safety states, as basic principle of grade-crossing protection, that ease of motor peration is essential and that artificial obstructions, bumps, or ɔgs in line of travel should be avoided on the score that they have roved to be ineffective in reducing speed and derailment accidents, nd that they distract the driver's attention, which should be ɔcused on looking for approaching trains.

General specifications for satisfactory grade crossings follow and re illustrated by Fig. 193 and 194.

SPECIFICATIONS FOR RAILROAD GRADE CROSSINGS

"**Signs and Signals.**—Uniform type of reliable audible and visible signals cated not more than 15′ from track, and about 4′ outside of the pavement ea on the right-hand side of traffic; height of signal to be adjusted for local nditions and type of signal. Two signals to be erected, one on each side of ossing; these signals to be supplemented by watchmen for at least 12 hr. villages and for at least 16 hr. daily on roads carrying over 3000 vehicles ily, where switching or station stops occur close to the crossing. The sible part of such signals to be of an oscillating or intermittent-flash type. l signals to be equipped with an automatic "Out of Order" sign properly uminated if anything goes wrong with the mechanism.

"Standard crossing signs to be located on signal standard and illuminated night by a steady hooded light to prevent glare into eyes of approaching ivers.

"Standard disc warning approach sign 300′ from crossing outside of pavement area on right-hand side of traffic line (not more than 3½ nor less than above grade of highway.

"Standard pavement markings.

"Special checkerboard warning sign 500′ from crossing if conditions arrant this extra sign.

"Highway traffic Stop Order signs within 50′ of rail enforced by police gulations for exceptional cases.

"**Pavement Width.**—At least 6′ wider between rails than on approaches. least 20′ for 50′ each side of rails.

"**Highway Alignment.**—Straight alignment at crossing and for at least ′ each side of crossing.

"Minimum radius of curvature on approaches 500′.

inimum acute angle between road and track center line preferably not less an 60 degrees.

"**Highway Grades.**—Maximum of 3 % for 75′ each side of crossing.

"Maximum downhill approach grade, 6 % with 200′ vertical-curve proach or 7 % with 300′ vertical approach.

"Maximum upgrade approach, 8 % with 200′ vertical-curve approach.

"**Sight Distance along Highway.**—Three hundred feet minimum.

"**Railroad Track.**—Where tracks are on tangent, all rails to be at same vations. Where more than one track exists and the rails are superelevated curvature the track elevations must be adjusted so that no severe bumps cur, which would tend to stall an automobile engine in high gear at low eed (or the top of rails should be in as near the same plane as possible).

"See Fig. 193 for typical grade-crossing approach."

Pavement or Planking between Rails.—The pavement between e rails of the track must be wide enough to prevent the wheels of ghway vehicles from running off the edge and striking the rail, th resultant stalling of the vehicle or its diversion from its normal line of travel along the highway. This is particularly important on skew-angle crossings.

Where the approach pavement is a curbed street, 2′ addition[al] width outside of the curb on each side for the pavement or plank[-]ing between rails should be sufficient. On rural highways wit[h] earth shoulders, the rail planking should be made wider than th[e] outside limits of the earth shoulder on which it is safe to driv[e]. On a well-traveled improved state road this usually requires 2[...] to 30′ width at right angles to the road center line.

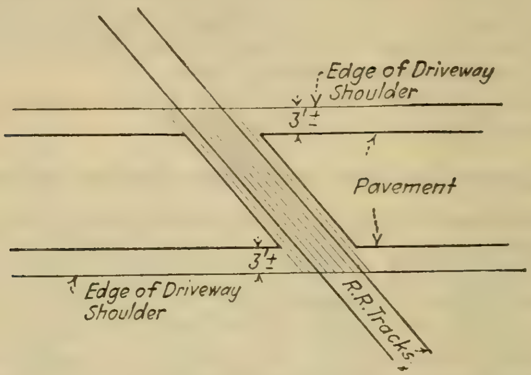


FIG. 195.—Planking between rails at crossing.

Well-kept planking or rails makes the most satisfactory crossin[g] but a cold-patch bituminous pavement carefully maintained serv[es] well if it has a firm, solid, grooved header along the rail gage whi[ch] can be easily obtained by the utilization of old rails as per sketc[h]. It is important that the paving between rails be a straight pla[ne] between top of rails. It is a common fault to curve it up, whi[ch] makes a bad bump.

FIG. 195*A*.—Ordinary cold patch pavement between rails wi[th] rail gruved header. Satisfactory if surface of cold patch is kept [in] a smooth level plane between rails.

Types of Signs and Signals. Approach Warning Signs.—A[n] well-placed legible sign of distinctive and uniform shape and legen[d] so that it readily catches the eye, and its shape as well as the lege[nd] indicates railroad crossing, will serve the purpose. Nation[al] uniformity in regard to shape, legend, and location is desirable.

These signs are usually placed about 300′ away from the tra[ck] and are located on the right-hand side of the pavement at an el[e]vation easily picked up by the eye and lighted at night by the usu[al] car headlight 2 to 3 ft. above the ground. See also page 687.

Figure 196 shows two popular types; the disc type, and th[e] checkerboard type. Figure 197 shows the usual location of su[ch] signs, which is 4′ off the pavement edge on rural roads and as clo[se]

to the curb as possible without an overhang of the sign into the street on curbed city or village streets. The sign is usually set at an angle of about 15° to improve visibility as the driver nears it. These signs cost about $10 apiece to install, and have a maintenance and renewal charge of about $2 per year.

Pavement Markings.—Pavement approach warning markings are intended as an additional safeguard, particularly at night, in case the driver fails to see the approach warning signs at the side of the road. Various legends and systems of stripes are used. Figure 198 shows a useful design which serves traffic well. National uniformity is desirable.

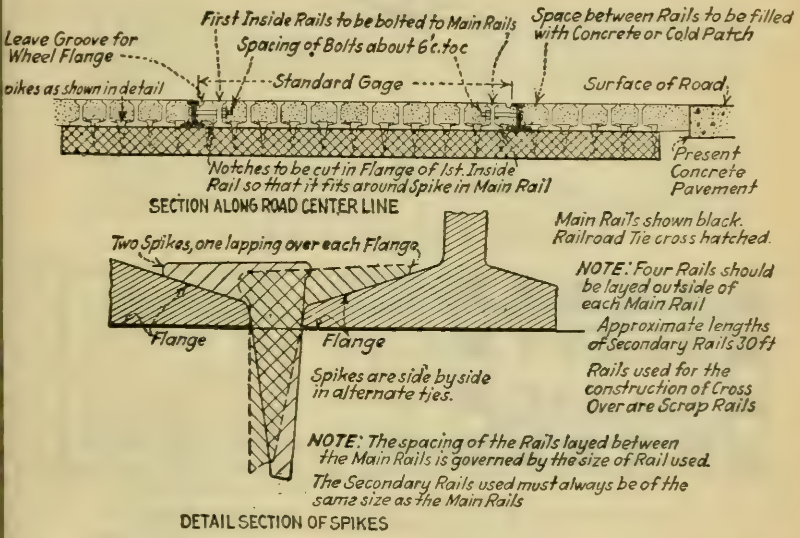


FIG. 195*B*.—A very excellent type of crossover using old rails surrounded with either cold patch or cement concrete.

These markings are made with the usual pavement-marking paint. On the usual road, one application a season will be enough. On heavy-traffic roads, two to three applications are required. The average cost for paint and labor per year per crossing is about $15 (1925 cost conditions).

Standard Crossing Signs.—Standard crossing signs vary for different railroads and different localities. The eastern states favor the cross or diamond sign and some localities favor the circular sign. National uniformity is desirable and should be arranged. The essential features of these signs should be large size, good location outside of the pavement area, and the use of two signs one on each side of the track as noted under the second cause of accident on page 606.

If automatic signals are used at the crossing, the standard crossing sign should be located on the same standard as the signal in order not to distract the driver's attention from the signal opera-

tion by two separate signs in different locations. All standard crossing signs should be illuminated at night by a steady hooded white or yellow light which does not throw a glare into the eyes of approaching drivers.

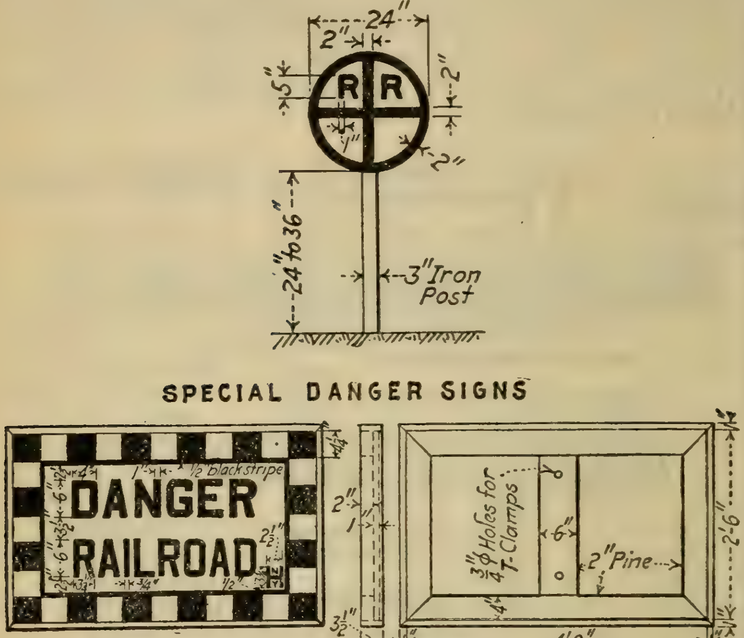


FIG. 196.—Typical approach warning signs.

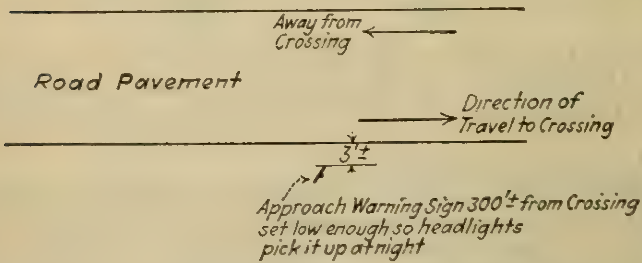


FIG. 197.—Location of approach warning signs.

Automatic Signals and Watchmen. *Limitations of Use.*—Automatic signals are primarily suited for the protection of crossings located between railroad station stops where trains are traveling at normal schedule speed. Under these conditions the signal warning has a short duration and always means that danger is

actually imminent, and under these conditions traffic respects the signal and gives it due consideration. Where automatic signals are used near station stops, or where yard or siding tracks are used for considerable switching, the signal indicates danger for long periods when no danger actually exists. This tends to discredit the warning with the traveling public and they give it little attention, which reduces the effectiveness of the signal not only at the crossing in question but tends to discredit similar signals in proper locations. For such locations the automatic signal should be supple-

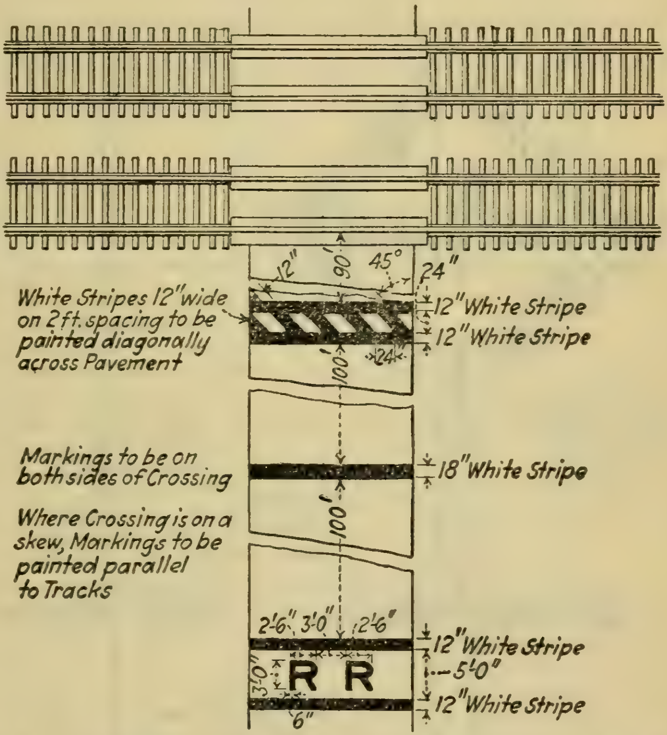


FIG. 198.—Pavement markings at railroad crossings. (N. Y. State, 1926.)

mented by flagmen during the portion of the day when the signal operation is made indefinite by long stops or switching.

Watchmen are particularly suited for use on heavily traveled highways where railroad trains either stop, switch, or shift continuously across the highway. The watchman can use judgment in moving traffic, and can safely speed up the movement of crossing traffic which reduces needless delay nuisance.

Conditions governing the proper use of signals or watchmen may be summarized as follows:

CONDITION	RECOMMENDED METHOD
Crossing between stops with trains traveling at normal schedule speeds.	Automatic signals.
Crossings near stations where stops or shifting occur for a large part of the time.	Automatic signals, supplemented by watchman part time or full time, depending on stop and switching schedule and volume of highway traffic.

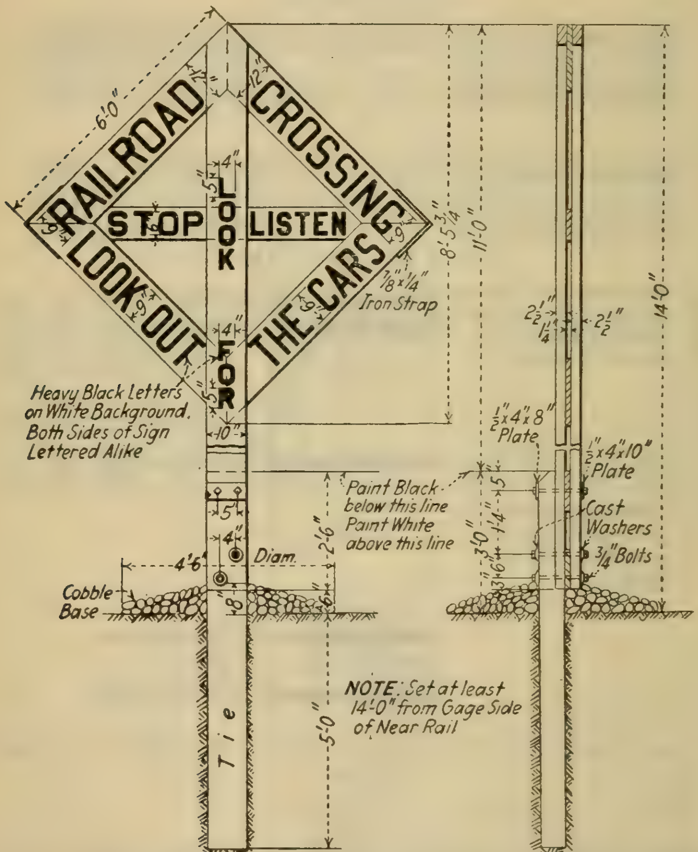


FIG. 199.—Standard diamond railroad crossing sign. Buffalo-Rochester and Pittsburg Ry.

Reliability of Protective Devices.—Mechanical devices have been perfected so that they are very reliable. All approved installations also automatically fall into the danger position if anything goes wrong with the circuits or mechanism.

Watchmen are subject to the human element of failure due to sickness or inattention. On heavily traveled crossings it has been found desirable to supplement the watchman with automatic signals to provide against this contingency. Under these conditions the automatic signal generally has a bell attachment to act as signal to the watchman as well as to the public.

Causes of Failure in Effectiveness of Protective Measures.— A common cause of accident is a wilful disregard of the warning on the part of the highway user, and there is no means of correcting this abuse except by police control.

The other causes are failure of signal or watchman to prevent accidents chargeable to failure of signal to function, too short a warning period, failure of driver to see or hear signal, failure of driver to understand signal, collision of road vehicle with signal posts or gates, and failure of signal to function due to unusual direction of train movements.

Failure of signal or watchman to function is a rare occurrence but does happen due to mechanical or human uncertainties. On heavy-traffic crossings, this can be overcome by the use of both automatic signals and watchmen, thus reducing the probability of failure to a very rare occurrence. Too short a warning period can be remedied by longer track circuits, giving about 25-sec. warning for the fastest trains on the line.

Failure of driver to understand signal is rare but occurs with sufficient regularity to warrant protection. It is largely due to non-uniformity of signal signs or lights, and a conflict between city street signals and rural railway-crossing signals. Gates or the oscillating disc and light signals are easily understood. The intermittent flashing light is sometimes confused with city isle-of-safety lights. It is suggested that the intermittent flashing red light be used only at railroad crossings to indicate imminent danger and that all isle-of-safety lights be steady yellow.

Failure to hear or see signal is due to type and location. Bell or hearing protection is obsolete, except as a minor adjunct, as motor traffic with closed cars and high speed gets little benefit from sound warning. The eye of a driver is more easily caught by a swinging disc or light or by an intermittent flash than by a steady light or steady semiphore arm in a danger position. The location of lights or oscillating discs must be well within the normal field of vision of the driver, which means as low as practicable without being obscured by rigs ahead of the driver, and as near the center of field of view as possible without causing an obstruction to the line of travel. These facts indicate that the most effective types of signal are the oscillating or intermittent-flash type supplemented by a bell attachment (see p. 618) located not more than 4′ off the edge of the pavement for rural conditions, the standards and crossing signs to be large enough and so painted that they catch the eye easily, the lights or swinging discs to be as low as practicable (see Fig. 201 and 202).

Collision between vehicles and stationary obstructions is quite frequent (see p. 35). Accident records in regard to central obstructions indicate the necessity of locating signal standards outside of

(text continued on page 620.)

TABLE 113.—SPEED AND DISTANCE TABLE[1]

Miles per hour	Time per mile		Feet per minute	Miles per hour	Time per mile		Feet per minute	Miles per hour	Time per mile		Feet per minute
	Minutes	Seconds			Minutes	Seconds			Minutes	Seconds	
100.00	0	36	8800	45.57	1	19	4013	29.50	2	02	2596
97.30	0	37	8562	45.00	1	20	3960	29.03	2	04	2552
94.74	0	38	8337	44.44	1	21	3911	28.57	2	06	2515
92.31	0	39	8123	43.90	1	22	3863	28.12	2	08	2474
90.00	0	40	7920	43.37	1	23	3811	27.69	2	10	2438
87.80	0	41	7726	42.86	1	24	3770	27.27	2	12	2400
85.71	0	42	7543	42.35	1	25	3724	26.87	2	14	2365
83.72	0	43	7368	41.86	1	26	3682	26.47	2	16	2330
81.82	0	44	7200	41.38	1	27	3641	26.09	2	18	2296
80.00	0	45	7040	40.91	1	28	3600	25.71	2	20	2262
78.26	0	46	6887	40.45	1	29	3559	25.35	2	22	2231
76.59	0	47	6741	40.00	1	30	3520	25.00	2	24	2200
75.00	0	48	6600	39.56	1	31	3480	24.66	2	26	2172
73.47	0	49	6468	39.13	1	32	3442	24.32	2	28	2138
72.00	0	50	6336	38.71	1	33	3406	24.00	2	30	2112
70.59	0	51	6212	38.29	1	34	3369	23.68	2	32	2085
69.23	0	52	6090	37.89	1	35	3334	23.38	2	34	2058
67.92	0	53	5973	37.50	1	36	3300	23.08	2	36	2032
66.66	0	54	5870	37.11	1	37	3265	22.78	2	38	2006
65.45	0	55	5775	36.73	1	38	3228	22.50	2	40	1980
64.29	0	56	5658	36.36	1	39	3203	22.22	2	42	1956
63.16	0	57	5562	36.00	1	40	3168	21.95	2	44	1934
62.07	0	58	5465	35.64	1	41	3134	21.69	2	46	1909
61.02	0	59	5368	35.29	1	42	3106	21.43	2	48	1884
60.00	1	00	5280	34.95	1	43	3078	21.17	2	50	1863
59.02	1	01	5192	34.61	1	44	3044	20.98	2	52	1841
58.06	1	02	5113	34.28	1	45	3017	20.70	2	54	1822
57.14	1	03	5025	33.96	1	46	2990	20.45	2	56	1800
56.25	1	04	4950	33.64	1	47	2955	20.22	2	58	1779
55.38	1	05	4875	33.33	1	48	2930	20.00	3	00	1760
54.55	1	06	4798	33.03	1	49	2904	18.46	3	15	1628
53.73	1	07	4720	32.73	1	50	2878	17.14	3	30	1506
52.92	1	08	4655	32.43	1	51	2851	16.00	3	45	1408
52.17	1	09	4590	32.14	1	52	2825	15.00	4	00	1320
51.43	1	10	4523	31.86	1	53	2807	12.00	5	00	1056
50.70	1	11	4462	31.58	1	54	2781	10.00	6	00	880
50.00	1	12	4400	31.30	1	55	2754	8.00	7	30	704
49.31	1	13	4338	31.04	1	56	2728	6.00	10	00	528
48.65	1	14	4279	30.77	1	57	2710	5.00	12	00	440
48.00	1	15	4224	30.51	1	58	2683	4.00	15	00	352
47.37	1	16	4165	30.25	1	59	2664	2.00	30	00	176
46.74	1	17	4107	30.00	2	00	2640	1.00	60	00	88
46.15	1	18	4061								

[1] WEISS, "Practical Railroad Maintenance," McGraw-Hill Book Company, Inc.

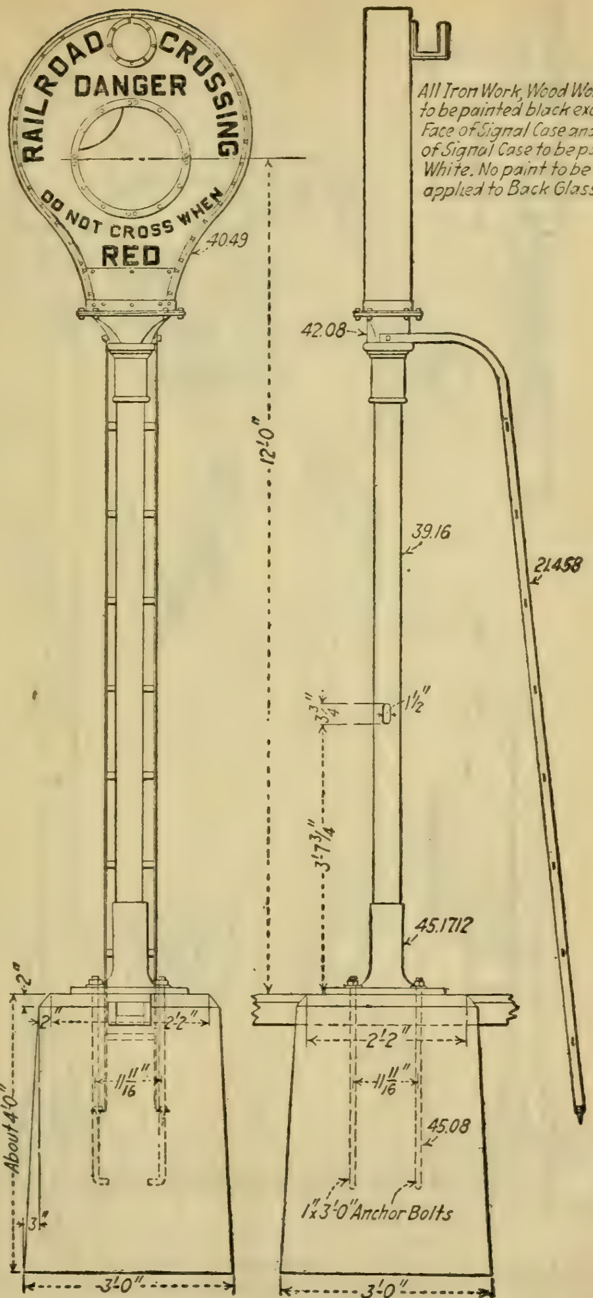


FIG. 200.—Banjo semiphore type of signal. (Lehigh Valley Ry. 1924.)

Note: This type of signal does not catch the eye so readily as the swinging disk or the automatic flash types and also 12 ft. is too high for easy vision particularly if auto has a sun hood.

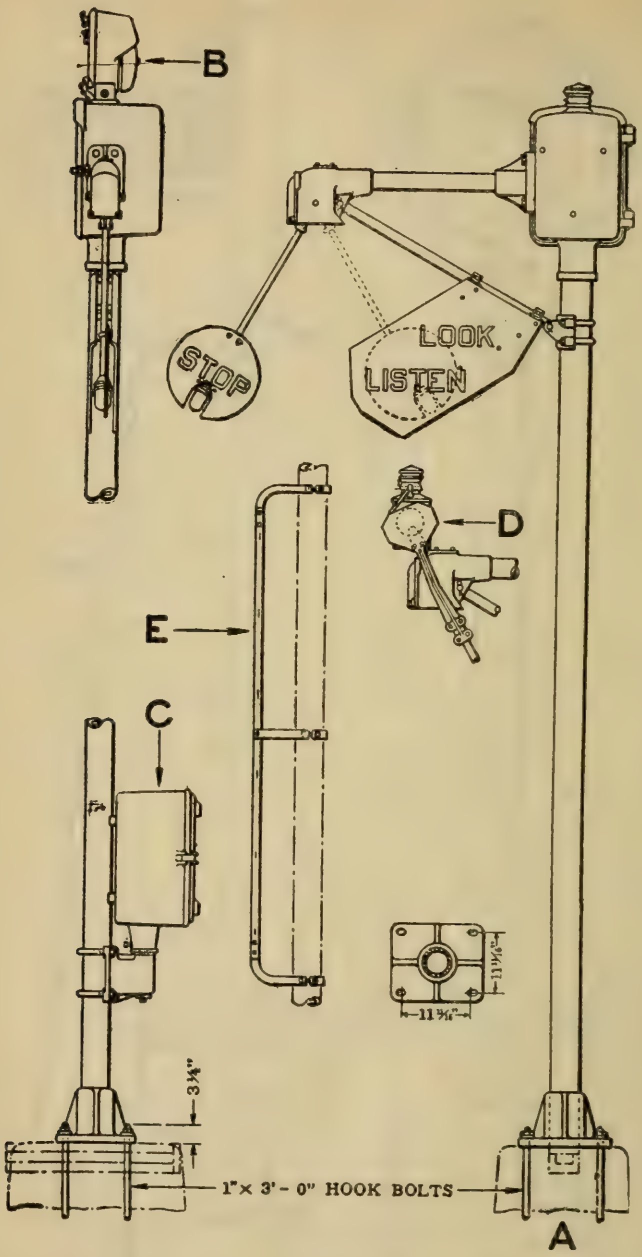


FIG. 201.—Highway signal. Oscillating disk and light. (Union Switch & Signal Co. Catalogue.)

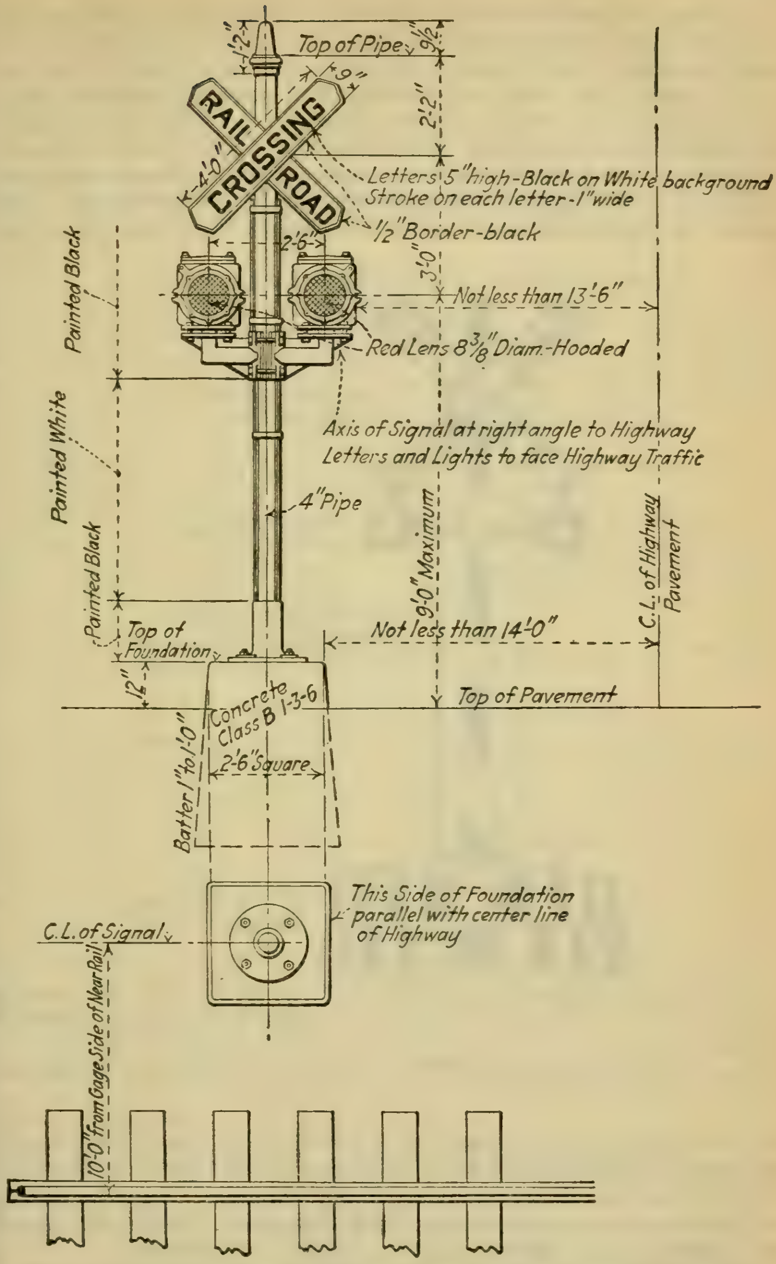


FIG. 202A.—Good typical design double flash signal for location at side of pavement rural highway crossings. (Buffalo-Rochester & Pittsburg Ry., 1926.)

the pavement area on rural highways. There is no question but what an automatic signal is more readily seen in the center of a road or street when it is actually flashing, but at night in rain or snow storms this location constitutes a positive menance when the lights are out and is the cause of enough accidents to nullify the visibility advantage of such a location. As a matter of fact, no cases are known in Division 4, western New York, where drivers failed to see the signals located on the side of the pavement. The central location also requires steady illumination, which is a bad

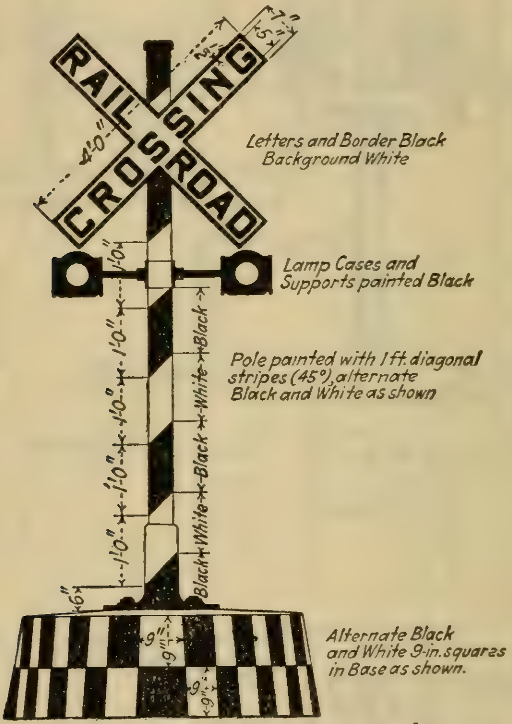


FIG. 202*B*.—Double intermittent flash signal with island base for location in center of streets. (Lehigh Valley Ry. Standards 1925.)

Note: Good design except that steady pilot lights are not shown.

feature during rain storms, as it blinds the eyes. The central location also adds about $1500 to $2000 to the cost of the installation for additional pavement approach widening. On wide village or city streets the central location is desirable, provided the standard carries steady warning lights as well as the flashers.

All automatic signals should be wired to take care of unexpected train movements in reverse direction to normal movement. This generally adds from $125 to $200 per installation on double-track roads, although in some cases it may add as much as $1000.

Types of Signals.—Bell signals alone are obsolete.

Plain, steady position semiphores (banjo type, Fig. 200) are fairly effective (see p. 617), but are going out of use in favor of the oscillating or intermittent-flash type.

Figure 201 shows a typical oscillating disc and light signal with bell attachment. These signals cost about $1300 to install per single signal, or about $2200 for two signals. Two signals should be erected at each crossing. The yearly maintenance is about $100 per year per signal. The signals are very effective (see p. 618).

Figure 202 shows a typical double horizontal intermittent-flash type of signal. These signals cost about $1500 for the erection of two signals (one on each side of track) on single- or double-track steam railroads, and about $2500 on electric railroads. The yearly maintenance is about $100 per year on steam roads and about $20 per year on electric roads. Where two or more highways intersect at the crossing, extra sets of lights should be provided facing each approach road. These signals are very effective and are the cheapest acceptable type to install and operate.

Specifications for these types of signal, covering all mechanical details of wiring, light intensity, lenses, and rapidity of flash or swing can be obtained from the American Railway Association, Signal Section, New York City. The essentials are as follows:

CODE PROPOSED BY SECTIONAL COMMITTEE OF THE AMERICAN ENGINEERING STANDARDS COMMITTEE

Section 4. Signals at Railroad Grade Crossings

"**Rule 40. Aspect.**—An electrically or mechanically operated signal used for the protection of highway traffic at railroad crossings shall present toward the highway when indicating the approach of a train the appearance of a horizontally swinging red light and (or) disc.

"NOTE.—This covers the use of so-called wigwags and of alternately flashing red lights, and the use of these devices should be restricted to the purpose of indicating the approach of a train.

"**Rule 41. Location.**—The railroad standard highway crossing sign and the signal shall be mounted on the same post.

"**Rule 42. Operating Time.**—Automatic signal devices for indicating the approach of trains shall be so arranged as to indicate for not less than 20 sec. before the arrival at the crossing of the fastest train operated on the track. Local conditions, such as three or more tracks, bad approaches, etc., should be allowed for by increasing the operating time, bearing in mind that too long an operation by slow trains is undesirable.

"**Rule 43. Flashing-light Type.**[1] *a. Height.*—The lamps should preferably be not less than 6′ nor more than 9′ above the surface of the highway.

"*b. Width.*—The two lamps shall be mounted horizontally, 2′ 6″ centers.

"*c. Flashes.*—Lights shall flash alternately. The number of flashes of each light per minute shall be 30 minimum, 45 maximum.

"*d. Hoods.*—Lamp units shall be properly hooded.

"*e. Range.*—When lamps are operated at normal voltage, the range, on tangent, shall be at least 300′ on a clear day, with a bright sun at or near the zenith.

"*f. Spread.*—The beam spread shall be not less than 3° each side of the axial beam under normal conditions. This beam spread is interpreted to refer to the point at the angle mentioned where the intensity of the beam is 10% of the axial beam under normal conditions.

"*g. Lenses or Roundels.*—The size shall be 5⅜″ minimum, 8⅜″ maximum.

"**Rule 44. Wigwag Type.**—*a. Length of stroke* is the length of cord which subtends the arc, determined by the center of the disc in its extreme positions, and shall be 2′ 6″.

[1] Good serviceable height, most cases 8′.

b. Disc.—The disc shall be 20″ in diameter. Its field shall be white with a black circumferential border 1″ wide. The horizontal and vertical diameters shall be shown by black lines 2½″ wide. A red lens or roundel should be placed at the center in front of the lamp.

"*c. Number of Cycles.*—Movement from one extreme to the other and back constitutes a cycle. The number of cycles per minute shall be 30 minimum and 45 maximum.

"*d.* The lamp with which the disc shall be equipped shall be lighted when the disc is swinging.

"**Rule 45. Approach Signal.**—Advance warning signals which indicate approach to a railroad crossing, and not the actual approach of a train, shal[l] conform to the provisions of sec. 3, Rule 30."

Section 5. Specifications for Colors

"**Rule 50. Definition of Colors.**—Red, yellow, green, or blue as used i[n] this code are intended to mean:

"*a.* The colors resulting from the transmission of the proper light throug[h] the proper glasses and having the characteristics described in Rules 51 an[d] 52.

"*b.* The colors resulting from the reflection of white light from the prope[r] pigments and having the characteristics described in Rule 53.

"NOTE.—For a definition of white light, reference is made to the repor[t] of the Colorimetry Committee of the Optical Society of America, 1920–192[1] (*Jour. Optical Soc. Amer.*, and *Rev. Sci. Inst.* 6, p. 563, 1922). Substantially, it is average sunlight at noon at latitude of Washington.

"**Rule 51. Qualitative Definition of Colors for Luminous Signals.**—*a Red.*—The spectrum of red shall contain both red and orange but not mor[e] than a trace of yellow and no green, blue, or violet. The most desirabl[e] hue is entirely free from yellow, which means that the glass does not transmi[t] the yellow light from a sodium flame.

"*b. Yellow.*—The spectrum of yellow shall contain red, yellow, and green with but little blue and no violet. The most desirable hue is entirely fre[e] from blue and might be designated a light amber.

"*c. Green.*—The spectrum of green shall contain yellow, green, blue, an[d] violet, with only a trace of red and orange. This hue is known as "admiralt[y] green" and has a bluish tint when observed by daylight.

"**Rule 52. Quantitative Definition of Colors for Luminous Signals.**—The colors red, yellow, and green shall have the following characteristics:

	Dominant wave length, millimicrons	Purity, %	Integral transmission of glass, %
Red	Not less than 624	Not less than 100	Not less than 10
Yellow	Not less than 592 nor more than 600	Not less than 97	Not less than 24
Green	Not less than 496 nor more than 536	Not less than 45	Not less than 11

"These values are determined by the transmission of light from a sourc[e] at the color temperature of 2.360°K. (practically that of the acetylene flam[e] or present type of vacuum tungsten lamp at normal voltage) through th[e] respective glasses. They are based upon spectral transmission measurements and upon computations carried out in accordance with the method and data described in the Colorimetry Report of the Optical Society o[f] America.

"NOTE.—The light and dark limits of the glasses on which the abov[e] values are based have the following relative transmissions on the scale of th[e] American Railway Association.

	Light Limit	Dark Limit
Red	300	150
Yellow	200	100
Green	250	100

"Rule 53. Quantitative Definition of Colors for Non-luminous Signs.— 'he colors red, yellow, green, and blue shall have the following characteristics:

	Dominant wave length, millimicrons	Purity, %	Integral of pigment, %
Red.........	Not less than 608	Not less than 60	Not less than 8
Yellow......	Not less than 580 nor more than 588	Not less than 80	Not less than 35
Green.......	Not less than 524 nor more than 552	Not less than 30	Not less than 8
Blue........	Not less than 466 nor more than 474	Not less than 10	Not less than 4

"These values are determined by the reflection of white light from the ›spective pigments. They are based upon spectral reflection measurements nder conditions of diffuse illumination and upon computations carried out . accordance with the methods and data described in the Colorimetry eport of the Optical Society of America."

Probability of Accident. *Danger Index.*—Probability of accident epends on volume of highway traffic, number and speed of trains, elay and congestion at crossing, visibility at crossing, physical ondition of highway approaches, and the method of protection used t the crossing. As a rough basis of arriving at a relative danger for large number of crossings which it is desirable to rate in order of nportance for a program of improvement the following method, sed in western New York, is described.

)anger index, unprotected crossings = Average 24-hr. highway traffic × Weighed value, of number trains 24 hr. × Visibility factor × Approach danger factor.

To find the probability of the number of serious accidents per ear (long-time average) the danger index for the crossing is divided y a special constant for each method of protection which repre-ents one serious accident per year and is derived from a careful udy of accident data for a large number of crossings for a num-er of years. Individual crossings will, of course, for short periods ften vary considerably from these results, but in the long run the alues are very reliable for this particular district. The tentative alues for the constants used are as follows (these values are, of ourse, subject to future correction based on more complete data):

'nprotected crossings.............................. 125,000
lain semiphore or banjo semiphore..................... 250,000
Vigwag or flash signals.............................. 500,000
4-hr. watchmen or gates.............................. 700,000

To illustrate, if a crossing has a danger index of 50,000, the robability of serious accident is obtained as follows:

Unprotected conditions $\dfrac{50{,}000}{125{,}000}$ = 0.4 accident per year.

Flash signals.......... $\dfrac{50{,}000}{500{,}000}$ = 0.1 accident per year.

Probable yearly accident damages can be approximated from this or any assumed average injury amount, say, $15,000 per serious ıjury.

The use of a danger index appears to some engineers at first sigh as of little real value and a complicated matter. In reality, it i simple and has been found to agree with average accident records fc a 10-year period and with the common-sense judgment of railroa and highway engineers. It has been adopted as the official stanc ard of rating the crossings for order of elimination improvemen The factors are explained as follows:

Highway-traffic Factor.—This is obtained from the yearly traffi census modified for probable 24-hr. year-round daily volume an corrected for probable increase during the period to be considere (see Chap. I, p. 32).

Railroad-traffic Factor.—For grade-crossing danger index th following values are used, which consider speed and delay conges tion:

Number passenger trains per 24 hr. full speed × 1.
Number passenger trains per 24 hr. near stops × 0.25.
Number freights full speed × 0.5 } highway traffic less tha
Number freights near stops × 0.25 } 2000 daily.
Number freights full speed × 0.75 } highway traffic 2000 t
Number freights near stops × 0.25 } 4000 daily.
Number freights full speed × 1.0 } highway traffic over 40c
Number freights near stops × 0.25 } daily.

Visibility Factor.—For good visibility where driver of roa vehicle can see 500′ each way along track when he gets to withi 70′ of the crossing a factor of 1.0 is used.

For a view of less than 500′ from each of the four possible dire tions of sight 0.1 is added to the factor, giving a maximum fact of 1.4.

The effect of visibility of approaching trains is very indefinit and there is no agreement among engineers as to values to b assigned. It is certain, however, that it is not directly proportion to degree of poor sight. All drivers use more care at a blind cros ing than at an open crossing unless the crossing is protected b watchmen or signals, in which case the invisibility of approachin trains has little effect on accident.

Where the crossing is unprotected it is necessary for the drive to see approaching trains with sufficient ease while he is still fa enough away from the crossing to get his car under control. It also necessary for him to get across the tracks, after the last tim he looks for trains, before an approaching train reaches the crossin The author's personal investigations of the habits of ordinaril careful drivers on improved roads (state system) indicates tha they cross the usual crossing at about 20 to 25 miles per hour an that the last time they look for trains is about 60 to 80′ from th first rail. If they see no trains they confine their attention t driving. If these assumptions are correct, safe visibility must b sufficient to permit the road vehicle to travel up to and across th tracks before a train, which could not be seen the last time th driver looked, reaches the crossing.

For usual single- or double-track crossings the road vehicle mus travel 100 to 200′ while the driver is not looking for trains. A

different speeds covering this distance would take the following times:

Speed, miles per hour	Time of crossing	
	100′ distance, in seconds	200′ distance, in seconds
10	7	14
15	4.5	9
20	3.5	7
25	2.7	5.4
30	2.3	4.6

The distance trains travel per second at different speeds is approximate as shown in the following table.

Speed, miles per hour	Feet per second	Required visibility for a six-second interval, in feet
20	30	180
30	45	270
40	58	350
50	73	450
60	88	530

A leeway of six seconds for a sight distance 70′ from the track should be the minimum safe interval for ordinary conditions. This interval requires visibility lengths (shown in the last column of the above train speed table) according to the speed of the approaching train.

Approach Factor.—For good approach conditions use factor of 1.0. If approach conditions are worse than the minimum requirements of specifications given on page 609, 0.1 is added for each side of crossing which does not meet specifications, giving a maximum factor of 1.2. The main danger is due to difficulty in stopping cars on a downhill grade when the pavement is slippery.

For example of figuring danger index see sample report p. 606.

ELIMINATION OF GRADE CROSSINGS

Order of Importance.—Grade crossings can be eliminated by means of grade separations and relocations. Road relocations can often be made at moderate cost, but grade separations are always an expensive proposition. As funds are always limited for such work, it is important to select the crossings for first consideration which give the most reduction in danger and delay per dollar expended, that is, any large program should be coordinated for relative danger, considering the installation of signal or watchman protection, and for best business investment, considering elimination construction. This can be readily approximated by means of careful preliminary estimates of cost of the most feasible methods of elimination in conjunction with the relative danger at the present

(text continued on page 630.)

TABLE 114A.—ELIMINATION PROJECTS ARRANGED IN ORDER OF GREATEST DANGER, STEAM RAILROADS

Order greatest danger	Danger index	Index map number of crossing	County	Town	Railroad	Branch railroad	Highway number or name
Road relocation (no structures)							
1	38,000	22 & 202	Livingston	Avon	Erie	Avon-Mt. M.	623 & 1030
2[a]	21,000	65	Livingston	Groveland	D. L. & W.	M. L.	8112
3[a]	20,000	(F.A.)85 & 205	Livingston	Nunda	Erie	M. L.	Dalton-Caline
4	10,500	172	Monroe	Mendon	L. V.	M. L.	1187
Existing dangerous eliminations							
1	10,000	163	Monroe	Perinton	N. Y. C.	West Shore	60
2	9,000	43	Orleans	Ridgeway	N. Y. C.	Falls Br.	5469
3	8,000	(F.A.)88	Genesee	Stafford	L. V.	M. L.	5145
4	6,000	24	Livingston	Conesus	Erie	Corning	828
5	2,200	52	Livingston	Groveland	Penn.	Roch.	9100
6[a]	2,000	182	Livingston	York	D. L. & W.	Switch	Retsot
7	1,500	120	Monroe	Greece	N. Y. C.	Falls Br.	148
Program for signals, watchmen, etc.							
1[b]	220,000	1[b]	Monroe	....	N. Y. C.	Main line	166
2[b]	180,000	142[b]	Genesee	Bat. City	N. Y. C.	Main line	Bat. City
3[b]	180,000	(F.A.)143[b]	Genesee	Bat. City	N. Y. C.	Main line	Bat. City
4[b]	150,000	99[b]	Monroe	....	N. Y. C.	Main line	1307
5[b]	100,000	118[b]	Monroe	....	N. Y. C.	Main line	574
6[c]	81,000	7[c]	Monroe	Henrietta	N. Y. C.	West Shore	62

7[b]	80,000	2[b]	Monroe	....	L. V.	Main line	648
8[d]	75,000	(F.A.)34[d]	Monroe	Riga	N. Y. C.	West Shore	634
9[b]	75,000	138[b]	Genesee	Le Roy Br.	N. Y. C.	Main line	Le Roy Br.
10[b]	73,000	(F.A.)4[b]	Genesee	....	B. R. & P.	Roch Div.	Ler. Village
11[c]	60,000	32[e]	Monroe	Chili	N. Y. C.	West Shore	79
12[b]	60,000	(F.A.)116[b]	Monroe	....	N. Y. C.	West Shore	5435
13[b]	43,000	11[c]	Genesee	....	N. Y. C.	West Shore	1402
14[ee]	40,000	(F.A.)6[e]	Monroe	....	N. Y. C.	Auburn Br.	776
15[c]	40,000	8[e]	Monroe	Henrietta	L. V.	Roch. Div.	62
16[c]	40,000	69[e]	Monroe	Gates	Penn.	Switch	63
17							
18[d]	38,000	17[f]	Orleans	Murray	N. Y. C.	Falls	5025
19[a]	36,000	159[b]	Monroe	....	N. Y. C.	Main line	634
20[b]	36,000	160[b]	Monroe	....	N. Y. C.	Main line	1236
21[b]	[illegible]	161[b]	Monroe	....	N. Y. C.	Main line	1390
22[b]	36,000	(F.A.)195[b]	Livingston	....	D. L. & W.	Main line	1248
23[d]	33,000	(F.A.)5[f]	Ontario	Farmington	N. Y. C.	Auburn	484
24[b]	30,000	57[b]	Ontario	....	L. V.	Main line	1415
25[b]	30,000	(F.A.)105[b]	Ontario	....	N. Y. C.	Falls & B. C.	Cana. City

[a] Means construct when road is improved.
[b] Means adequate signals exist.
[c] Unprotected.
[d] Means existing signals insufficient.
[e] Means eliminations ordered.
[f] Existing signals fairly good.

NOTE. Letters F.A. before map number means on federal-aid system.

NOTE. Condition of signals tabulated for Jan., 1923.

TABLE 114*B*.—ELIMINATION PROJECTS ARRANGED IN ORDER OF BEST BUSINESS INVESTMENT, STEAM RAILROADS

Order best business investment	Investment index	Index map number of crossing	County	Town	Railroad	Railroad of branch	Highway number or name
Road relocations (no structures)							
1[a]	(F.A.)$0.50	85 & 205	Livingston	Nunda	Erie	M. L.	Dalton-Hornell
2	1.60	22 & 202	Livingston	Avon	Erie	Avon-Mt.M.	623 & 1030
3[a]	1.65	65	Livingston	Groveland	D. L. & W.	M. L.	8112
4	1.90	172	Monroe	Mendon	L. V.	M. L.	1187
Existing dangerous eliminations							
1[a]	$ 5.00	182	Livingston	York	D. L. & W.	Switch	Retsof
2	5.00	88(F.A.)	Genesee	Stafford	L. V.	Main line	5145
3	6.80	43	Orleans	Ridgeway	N. Y. C.	Falls Br.	5469
4	10.00	24	Livingston	Conesus	Erie	Rochester Corn.	828
5	10.00	163	Monroe	Perinton	N. Y. C.	West Shore	60
6	33.00	120	Monroe	Greece	N. Y. C.	Falls Br.	1481
7	45.00	52	Livingston	Groveland	Penn.	Rochester Div.	9100
New eliminations, subways or overhead (on present system, 1924)							
1[b]	$0.85[c]	1[b]	Monroe	Brighton	N. Y. C.	Main line	166
2[b]	1.25[c]	99[b]	Monroe	Perinton	N. Y. C.	Main line	1337
3	1.30[c]	2	Monroe	Rush	L. V.	Main line	648
4	1.60[d]	7	Monroe	Henrietta	N. Y. C.	West Shore	62
5	1.75[e]	34(F.A.)	Monroe	Riga	N. Y. C.	West Shore	634
6	2.20[c]	4(F.A.)	Genesee	Le Roy	B. R. & P.	Roch. Div.	Le Roy

7[f]	2.50[e]	6[f](F.A.)	Monroe	Pittsford	N. Y. C.	Auburn	766
8[f]	2.25[e]	11[f]	Genesee	Oakfield	N. Y. C.	West Shore	1402
9[b]	2.65[c]	138[b]	Genesee	Bergen	N. Y. C.	Main line	Le Roy-Bkport
10	2.75[d]	8	Monroe	Henrietta	L. V.	Roch. Div.	62
11	2.85[d]	32	Monroe	Chili	N. Y. C.	West Shore	79
12[b]	3.25[d]	69[b]	Monroe	Gates	Penn.	Switch	63
13	3.50[c]	60	Genesee	Bethany	D. L. & W.	M. L.	1268
14	3.60[g]	17	Orleans	Murray	N. Y. C.	Falls Br.	5025
15	3.75[e]	70(F.A.)	Livingston	Geneseo	Erie	Avon-Mt. M.	1247
16	3.90[c]	160	Monroe	Chili	N. Y. C.	M. L.	1236
17	4.15[c]	3	Monroe	Mendon	L. V.	M. L.	493
18	4.20[e]	161	Monroe	Gates	N. Y. C.	M. L.	1390
19[b]	4.20[c]	195[b](F.A.)	Livingston	Leiscester	D. L. & W.	M. L.	1248
20	4.25[g]	5 & 516(F.A.)	Ontario	Farmington	N. Y. C.	Auburn & Elect.	484
21[h]	4.25[h]	(F.A.) 12[h]	Genesee	Alexander	D. L. & W.	M. L.	8177
22	4.60[d]	38(F.A.)	Livingston	Caledonia	Penn.	Roch. Div.	5273
23	4.65[e]	58	Genesee	Elba	N. Y. C.	West Shore	8041
24	4.70[d]	20(F.A.)	Wyoming	Gainesville	Erie	Buf.-Corn.	5400A
25	4.80[c]	72	Livingston	Mt. Morris	D. L. & W.	M. L.	622 & 855

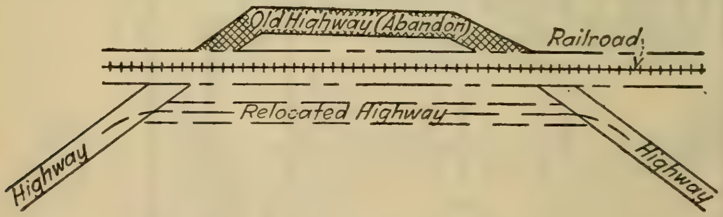
[a] Means construct when road is improved.
[b] Means located in villages or bad physical conditions which will normally delay construction.
[c] Means adequate signals exist.
[d] Unprotected.
[e] Means existing signals insufficient
[f] Means ordered by Public Service Commission.
[g] Existing signals fairly good protection.
[h] Means constructed.
NOTE. Letters F.A. before map number mean on federal-aid system.

crossings estimated in some manner approximately similar to th danger-index method given on page 623. A relative best busines investment index can then be established for each crossing by divic ing the cost of construction by the danger index and the crossing arranged in order of relative value (see tabulation 114*B*).

To illustrate again from western New York where this method in official use on the state road system program the following quoted from the official report on the Proposed Eliminatio Program:

"The general method of determining the relative value of eliminatic projects is based on dividing the cost of the proposed elimination for eac crossing, which ranges from $50,000 to $250,000, by the danger-index numb for that crossing, which ranges from 200,000 to 500. While this, course, is not rigidly applicable, it divides the crossings into rough gener classifications of relative effective expenditure, as the index numbers range from 40 cts. to $160 for new eliminations and from $5 to $40 for the improv ment of dangerous existing eliminations. All crossings in the division we then tabulated in the order of their best business-investment order, dividir the tabulation into two parts, one for new eliminations and one for tl improvement of dangerous existing eliminations. The crossings for eac railroad were similarly tabulated. The crossings in each county we similarly tabulated. In this way expenditures can be apportioned counties and to the different railroads without undue favoritism, and at tl same time the most important crossings selected for first consideratio The value of such data has been amply proved in this division during 19 in connection with recommendations for action in six petitions. Based c this program we advised quick action on three projects near the top of tl list at an estimated total cost of $225,000, which are well worth the expenc ture, and advised indefinite delay with signal protection on three projec well down on the list which are comparatively unimportant and would ha cost $300,000."

Consolidation of Crossings and Eliminations by Relocatio In many cases highways which are traveling in the same directic



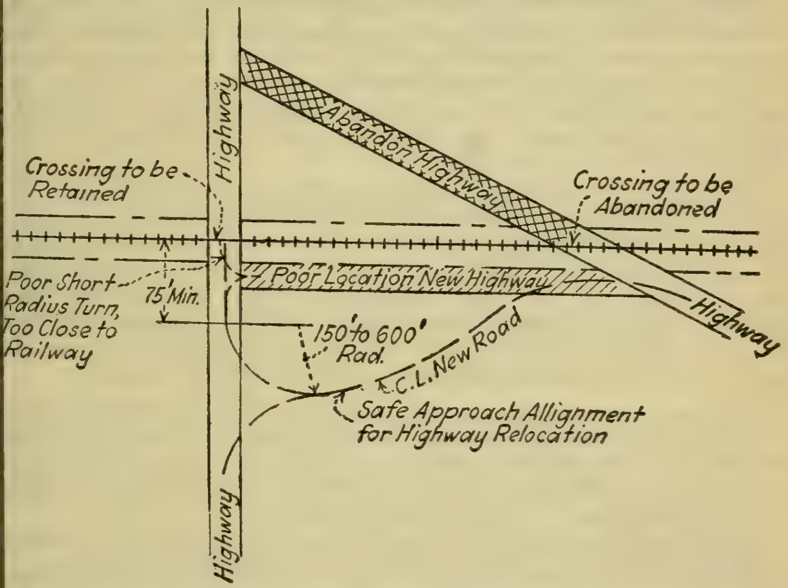
SKETCH A.—Relocation elimination.

as a railroad cross the railroad needlessly as shown in sketch A For such cases it is obviously desirable to relocate to avoid crossin provided it is physically possible and provided the new highway properly designed for easy alignment, grades, widths, etc.

In many cases it is possible to consolidate crossings as shown i sketch *B*. This method is not necessarily desirable, nor does necessarily reduce danger unless the number of times a vehicl crosses the railroad is reduced or unless the crossing which i retained is an easier, better protected, and safer crossing than th one abandoned. This requires careful engineering location an excellent design of the new proposed approaches of the highwa

relocation. That is, the use of one crossing for the same amount of traffic as previously handled by two crossings is just as dangerous as the original two crossings unless approach and protection conditions are improved. Accident records show that accidents are approximately directly proportional to the volume of highway traffic for any given condition of sight distance, approach grades, visibility, and number and speed of trains.

Sketch *B* shows examples of both poor and good relocation approach layouts. The poor layout is often advocated by the railroads as they require less right of way. Poor location of this



SKETCH B.—Relocation consolidation of crossings.

character are extremely dangerous as drivers cannot see trains approaching from the rear, and the short abrupt turn at the crossing gives them little opportunity to look up the track before they are on the crossing.

The long radius balloon-curve approach with a minimum tangent of 75′ from the track makes the approach safe. The radius of the approach curve should be varied according to the relative importance as required (see alignment specifications, p. 120).

See page 775 for official report on a relocation proposition.

SUMMARY OF GENERAL PRINCIPLES OF ELIMINATION OF CROSSINGS BY MEANS OF SIDE-LINE CONSOLIDATIONS

1. The crossing retained must be safer than the crossing abandoned.
2. The road design of the new connecting road must be up to reasonable engineering standards and must be particularly good in regard to approach alignment and grades at the retained crossing, permitting good car control and ample time for drivers to sense the approach of trains or to see automatic signals.

3. If there is a large difference in highway traffic volume on the two roads to be consolidated, the crossing on the heaviest traffic highway should be the one retained and improved.

4. If the traffic on both roads is practically the same and is light volume and if the crossings are of equal safety, the retained crossing should be selected to result in the least increase in distance of travel for highway traffic.

5. If the traffic is practically the same for both roads and is heavy traffic it is often better to protect each crossing by automatic signals or by eliminations rather than to attempt to consolidate them, on account of congestion, added distance, and inconvenience to traffic. That is, it is not permissible to consolidate crossing solely on the score of reducing the number of crossings when such action is a distinct detriment to the efficiency of the highway layout.

Subway and Overhead Elimination Specifications.—As structural eliminations are expensive and comparatively permanent, they should be carefully designed to provide adequate safety and comfort for both highway and railroad traffic. Provision should also be made for additional railroad trackage and a highway roadway width which will handle the expected growth in volume of travel during the life of the structure.

In the past there have been too many cases where such eliminations were designed solely from the railroad standpoint of getting rid of collisions at grade crossings with a consequent reduction in damage claims and without any serious consideration of safe highway conditions at the new elimination. That is, steep highway grades, crooked alignment, and narrow bridges at poorly designed eliminations have resulted in as many serious injuries to highway users as occurred at the old grade crossings due to collisions.

To illustrate the uselessness of poorly designed structural eliminations in reducing accidents the following accident statistics for 1926 on the state highway system in western New York (Division 4) are cited.

215 grade crossings—15 serious injuries or 0.07 injury per crossing average
10 poor dangerous eliminations, sharp curvature and narrow bridges 4 serious injuries or 0.4 injury per elimination
16 fairly good eliminations, 3 serious injuries or 0.2 injury per elimination
29 good eliminations—A few minor accidents but no serious injuries.

As a general rule, subways (highway under railroads) are safer than overhead crossings. The main reasons for demand for eliminations in this territory are to give free and safe access to new real estate development territory and to prevent delay and congestion on heavily traveled roads.

Provisions for future traffic growth is a vital part of the design. Too much liberality results in running the initial cost up beyond reason, and too little provision results in congestion and danger in a short period. As eliminations *in rural districts* are really luxuries instead of necessities they may better be dispensed with entirely unless they are made safe for a reasonable term of years. It is poor policy to run the initial cost up needlessly by too liberal design for future requirements for any portion of the structure which can be gradually widened to take care of future traffic growth without necessitating the complete rebuilding of the entire structure. That is, approach fills can always be widened at any time to get additional traffic lanes. Stringer type overhead bridges can be widened at any time without rebuilding the entire bridge. Additional trackage can be provided through a trestle approach span at any time by the construction of special walls which in no way disturb the old structure. The author has been in the habit of allowing for

o years' traffic growth for portions of the design which can be xpanded without loss and allowing for 50 years' growth for strucures which will have to be rebuilt entire to widen (see p. 32 for iscussion of future traffic).

The following specifications indicate minimum requirements ecessary for reasonably safe and convenient elimination designs.

SPECIFICATIONS FOR GRADE-CROSSING STRUCTURAL ELIMINATIONS

NOTE.—In the following specifications "subway" means where the high-ay passes under the railroad and "overhead" means where the highway asses over the railroad. The daily traffic volumes given refer to 12 hour aylight counts taken on Friday and Saturday in August.

General Specifications

As a general rule the elimination layout shall conform to normal highway cation and alignment. The introduction of curved highway approach ignment solely for the purpose of reducing span and cost of bridge strucires is rarely justified.

As a general rule, subways are to be preferred to overhead crossings on the ore of highway safety, appearance in villages, and urban property values nless the cost is materially greater than an overhead elimination. Subway iminations, however, must not have piers or column obstructions within e pavement area.

Fill approaches for overhead crossings are preferred to trestle approaches nless cost is materially increased due to property damage. This does not pply to single-approach trestle spans to reduce abutment costs.

Bridge Specifications and Clearances

ıbway Clearances (Railroad Bridges):	
Vertical clearance, crown of road to bottom of railroad bridge.	
Main roads	14′
Secondary roads	13.5′
Width of roadway at right angles to highway center line:	
Main roads (over 9,000 vehicles daily),	42′ minimum
Main roads (6,000 to 9,000 vehicles daily),	32′ minimum
Main roads (up to 6,000 vehicles daily),	26′ minimum
Unimportant roads (up to 300 vehicles daily),	20′ minimum
Sidewalks where needed,	5′ minimum
verhead Elimination Clearances (Highway Bridges):	
Vertical clearance, top of rail to bottom of highway bridge:	
Steam railroads:	
Normal	22.0′
Minimum	21.0′
Electric trolleys:	
Normal	16.0′
Minimum	14.0′
Highway bridge portal clearances:	
Main roads	14.0′
Secondary roads	13.5′
Side railroad clearances, outside rail to face of highway bridge abutment or pedestals:	
Steam railroads:	
Straight main track, minimum	8′
Usual practice	10′
Straight siding track, minimum	6′
Curved main track, minimum	10′
Electric trolley lines:	
Straight track, minimum	4′
Curved track, minimum	6′
Railroad bridge widths:	
Center to center of girders single track on tangents.	15′ 06″ to 17′ 06″ ±
Center to center of girders double track on tangents	30′ 06″ ±

Increase for curvature and length of span.

Highway bridge roadway widths, minimum:

Main roads (over 9,000 vehicles daily)	40′
Main roads (6,000 to 9,000 vehicles daily),	30′ minimu
Main roads (up to 6,000 vehicles daily),	24′ minimu
Unimportant roads (up to 300 vehicles daily),	20′ minimu
Sidewalks as needed in villages and all roads carrying over 2,000 vehicles daily, minimum	5′

Depth of Bridge Floors (Approximate Only for Preliminary Layouts):

Railroad plate girders, bottom rail to bottom of girders (through girder):

Steam railroads	3.5–4.0′
Electric railroads	3.0–3.5′

Deck girders 1/12 of span plus 18″:

Overhead highway bridges	3.0–4.0

NOTE.—Overhead highway bridge floor system encased in concrete protect from engine gases for main span over track. Use stringer type bridge up to 55′ clear span to permit easy future widening.

All railroad bridges to have solid floors to prevent falling of objects or road.

Bridge Design Loadings:

Highway bridges:	
Main roads	H-20
Secondary roads	H-15
Railroad bridges:	
Steam (main lines)	E-70 or E-
Steam (branch lines)	E-60 or E-
Electric interurban	E-40 to E-

Highway Approach Specifications

Minimum Sight Distance:

Main roads	350′
Secondary roads	250′

Alignment:

Main roads (straight if possible):	
Minimum center-line radius:	
On grades less than 5%	570′
On grades 5% or greater	800′
Side road intersections, minimum:	
Radius of curvature	50–350
(See p. 121 for discussion of intersections)	
Driveway connections, radius	25–35′
(See p. 121 for discussion of drive alignment)	

Maximum Grades:

Subways:	
Main roads, good alignment	6.0%
Secondary roads, good alignment	7.0%
Overheads:	
Main roads, good alignment	5.0%
Secondary roads, good alignment	6.0%
Electric railroad maximum grade	4.0%

NOTE.—Reduce grades for alignment sharper than stipulated abo A combination of a 6% grade on a 7 deg. curve (800′ radius) is the maxim permissible combination which serves satisfactorily. If sharper curvat is needed reduce grade. (See p. 118 for discussion.)

Minimum Length of Vertical Curves:

100′ for each 4% difference in gradients at bottom of hills

125′ for each 4% at top of hills

Carry road grade vertical curve across overhead bridges and make f surface coincide with this vertical curve

Roadway Widths (Minimum):

Pavements:	
Main roads, over 9,000 vehicles daily	40′
Main roads, 6,000 to 9,000 vehicles daily	27′
Main roads, 4,000 to 6,000 vehicles daily	20′
Main roads, up to 5,000 vehicles daily	18′
Unimportant roads	16′

Pavement under railroad bridges full width abutment to abutment, for length of runoff to normal width see page 133.

Grading:

Ditch to ditch in cut:

Two-lane traffic	26–32′
Three-lane traffic	36–42′

Top edge to edge of fills:

Two-lane traffic, up to 6,000 vehicles	32′
Three-lane traffic, 6,000 to 9,000 vehicles	42′
Unimportant roads	24′

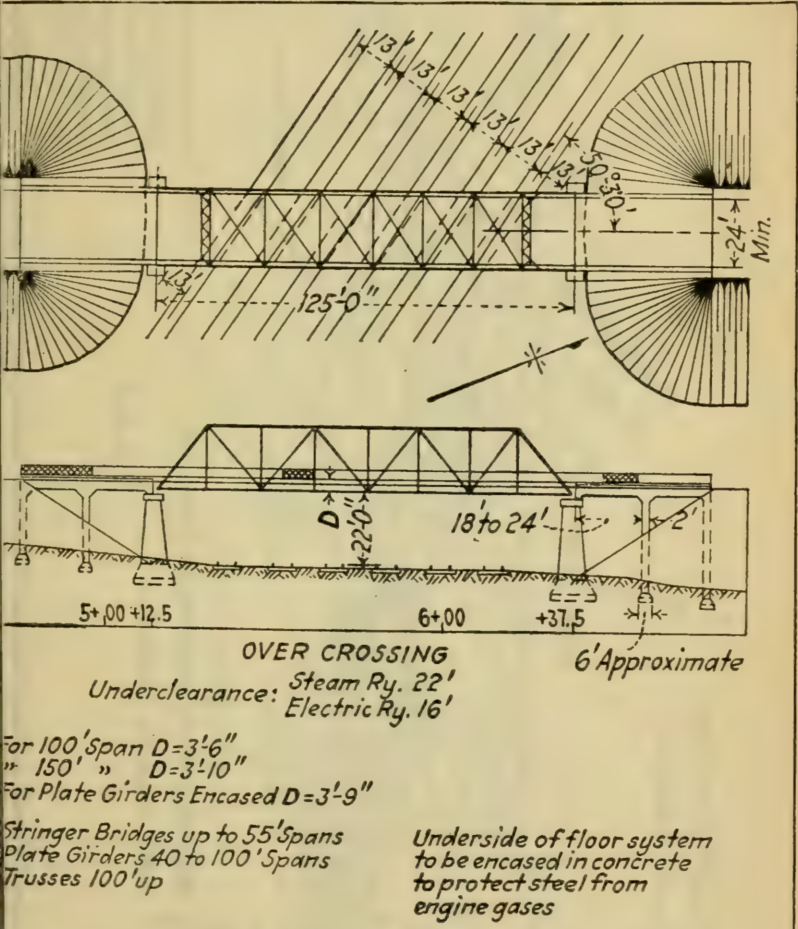


FIG. 203.—Typical overhead highway bridge clearances.

Sidewalks: Complete segregation from roadway by pipe rail and high raised curb (at least 12″ in subways) and by means of a separate lane fenced off by substantial rail on overhead fills.

Pavement Types: Main roads over 2,000 vehicles daily. Use rigid type of pavement in subways. Use temporary flexible type of pavement (gravel or macadam) on deep approach fills, later replaced with a rigid type after fill has settled.

(text continued on page 641.)

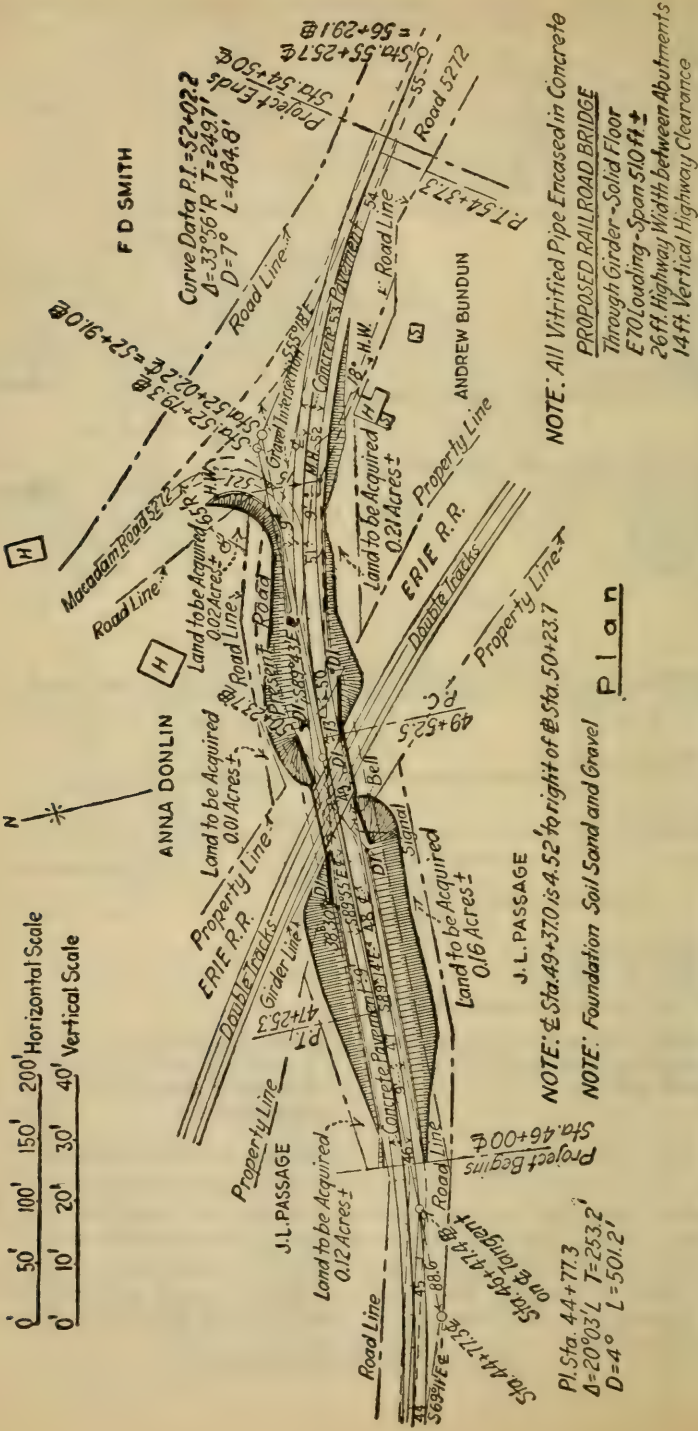


FIG. 204.—Typical subway layout Highway under railroad Rural road conditions.

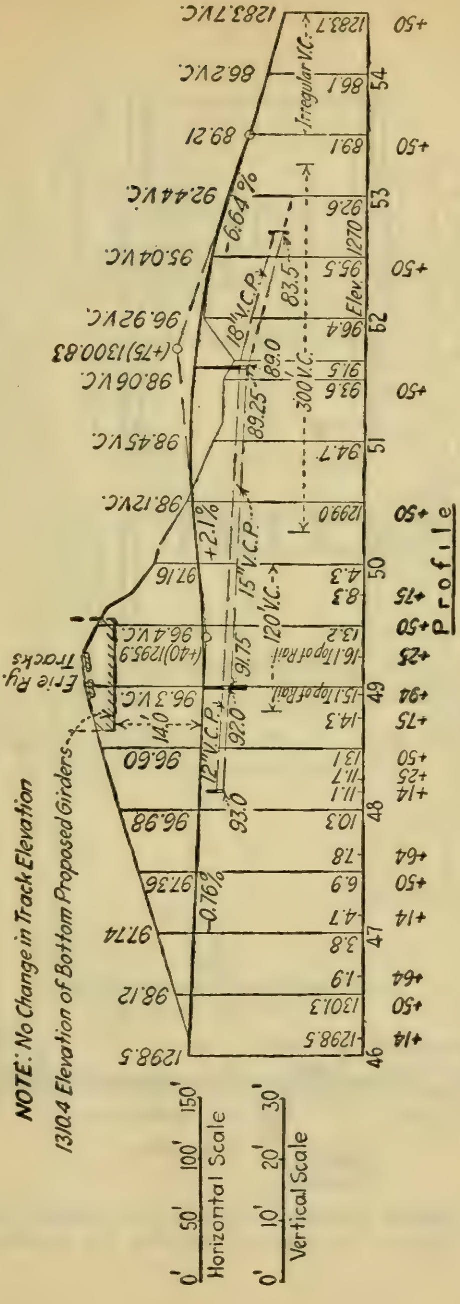


FIG. 204.—(*Continued.*)

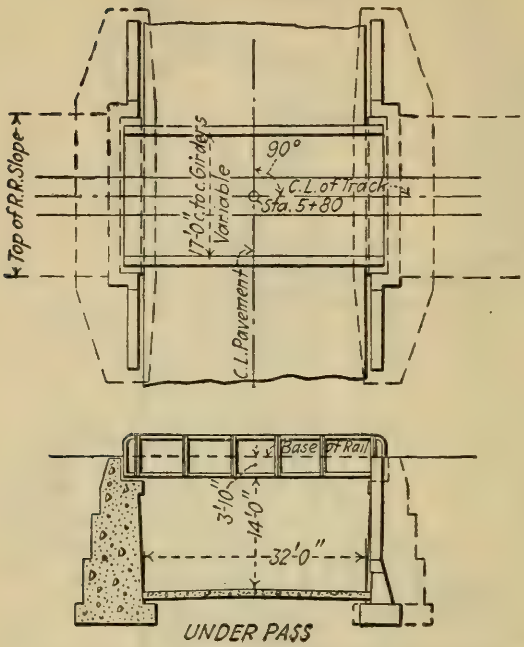


FIG. 204A.—N. Y. State standard underpass clearances rural state highways (1926).

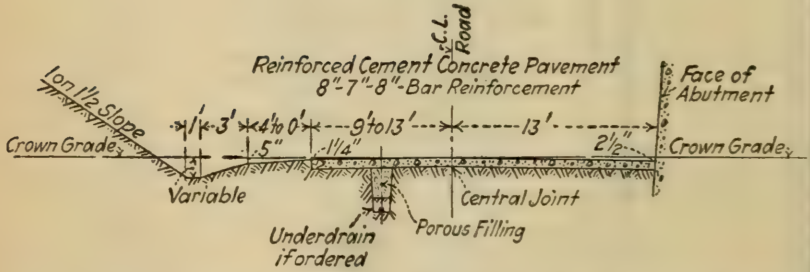


FIG. 205A.—Typical roadway section for subway elimination in rural districts—no special provision for pedestrians.

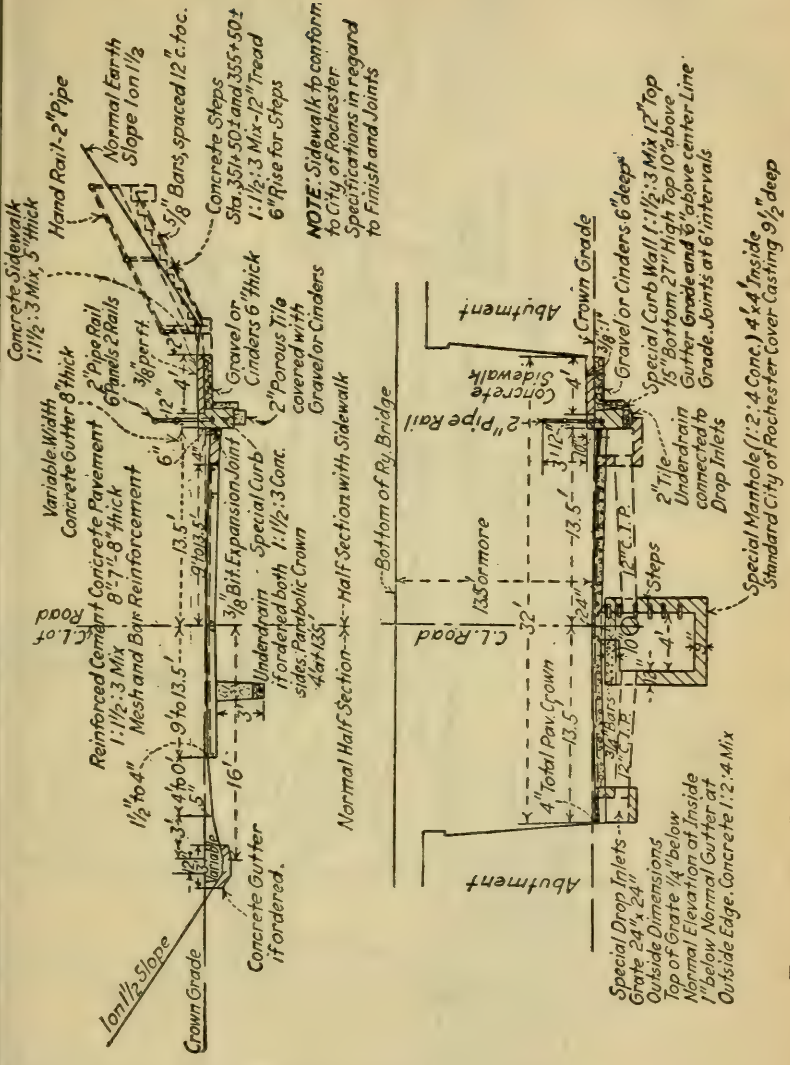


FIG. 205B.—Typical subway road sections pedestrian traffic rural districts.

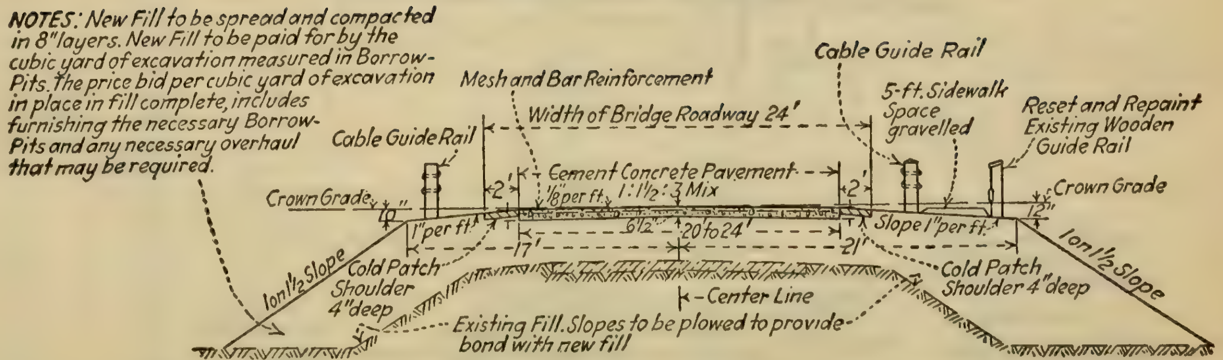


FIG. 206.—Typical roadway section for overhead elimination on main road with provision for pedestrians.

SPECIFICATIONS.—*(Continued.)*

Secondary roads, up to 2,000 vehicles daily, macadam or gravel.

NOTE.—For depths of pavements on different soils and for different traffic see Table 74, page 391 and Table 86, page 426.

Drainage: In subways pick up water on both sides of bridge to keep low spot dry. Never run water through on the surface and collect on one side unless road grade is on a continuous down grade for the entire elimination approaches.

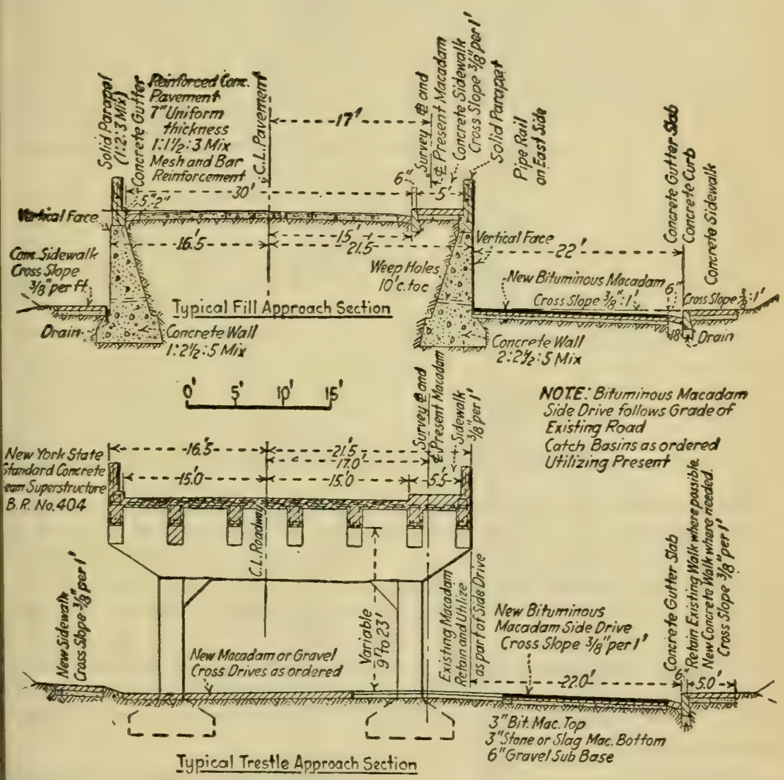


FIG. 206A.—Typical rural roadway approach section for overhead highway eliminations. (Village conditions.)

Miscellaneous Track and Clearance Data.—For side and vertical clearances see Specifications (p. 633).

The following typical roadway sections and track gage and center-line spacing are useful in connection with layouts.

Table 115.—Spacing of Tracks C to C Center around Curve to Allow for Overhang of Cars and Obtain Equivalent to That on Straight Track[1]

Centers on tangent track		Curvature in degrees															
		1		2		3		4		5		6		7		8	
Feet	Inches	Feet	Inches	Feet	Inches	Feet	Inches	Feet	Inches	Feet	Inches	Feet	Inches	Feet	Inches	Feet	Inches
12	00	12	1	12	3	12	5	12	6	12	8	12	9	12	10	13	0
12	6	12	7	12	9	12	11	13	0	13	2	13	3	13	4	13	6
13	00	13	1	13	3	13	5	13	6	13	8	13	9	13	11	14	0

Centers on tangent track		Curvature in degrees													
		9		10		12		14		16		18		20	
Feet	Inches	Feet	Inches	Feet	Inches	Feet	Inches	Feet	Inches	Feet	Inches	Feet	Inches	Feet	Inches
12	00	13	2	13	4	13	6	13	9	14	1	14	4	14	[illegible]
12	6	13	8	13	10	14	0	14	3	14	7	14	10	15	[illegible]
13	00	14	2	14	4	14	6	14	9	15	1	15	4	15	[illegible]

[1] *Weiss*, Practical Railway Maintenance, McGraw Hill Book Company, I:

Preliminary Investigations.—Preliminary investigations co\ trial estimates for all feasible schemes of elimination to pick t best and most economic solution. They must consider the possib ities of road relocations, subways or overhead methods, differe combinations of alignment and grade property damage, draina pavement types, etc. These investigations should be made experienced engineers, as they set the general plan and control t economics of design. A sample report follows and is supplement by various diagrams for quick estimating in comparing differe possible layouts.

MEMORANDUM FOR ———, PROPOSED GRADE-CROSSI ELIMINATION, CROSSING 34, STA. 2 + 00 + CHURCHVILLE VILLAGE, C. H. 634, NEW YORK CENTRAL RAILROAD (WEST SHORE BRANCH) MONROE COUNTY

"**Recomendation.**—I recommend that this crossing be eliminated in 19 by means of an overhead highway crossing.

"**Cost.**—The cost of this elimination, including property damage, is es mated at $133,000.

"The cost of the highway approaches and temporary side road is es mated at $63,000; the bridges and trestle at $52,000.

"The transmission line work at $5000 and property damage at $13,000

"The preliminary program estimate of February, 1924, was $120,0 including property damage. The preliminary program estimate of Mar 1925, was $130,000.

"**Status of Crossing.**—This crossing is first in order of importance Division 4 for new elimination projects and should be constructed in 19 regardless of the success or failure of the pending bond issue. The c

(text continued on page 644.)

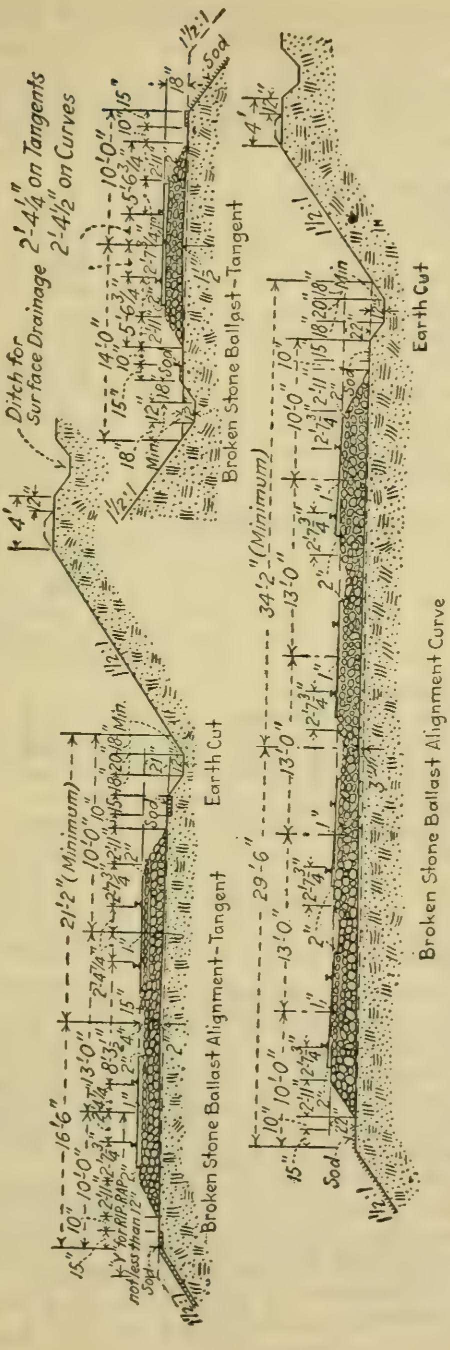


FIG. 207.—Typical railroad roadbed sections.

struction of this elimination cleans up all crossings on the main Rochester-Buffalo road between Rochester and Batavia.

"This crossing has a danger index of 75,000 and an investment index of $1.75.

"The immediate elimination of this crossing has been formally requested by the Rochester Chamber of Commerce, the Rochester Auto Club, the county of Monroe, the town of Riga, the Batavia Auto Club, and the county of Genesee.

"Physical Conditions at Crossing.

Number of tracks	2
Balast	stone
Weight of rail	110
Alignment of railroad	straight
Approximate track grade	level
Number of passenger trains	4
Speed of passenger trains	30 m.p.h.
Number of freight trains	40±
Speed of freight trains	25 m.p.h.
Present crossing protection	Watchman 8:30 a.m. to 5:30 p.m.
Angle center line and center-line road	36°±
Highway approach grades west	−3.3% east + 0.8%
Present highway pavement	Topeka on concrete 16′ wide

"Highway Traffic (12-hr. Counts in August).

	Year		Number of Vehicles
	1920		450
	1923		405
	1924		1677
Est.	1926	Est.	2000 to 2500 on completion of route to Batavia

"Visibility of Approaching Trains.

50′ east of tracks,	north 5000′,	south 3000′
100′ east of tracks,	north 600′,	south 600′
50′ west of tracks,	north 2000′,	south 2000′
100′ west of tracks,	north 1000′,	south 200′

"Accident Record.—Two minor accidents in 10 years.

"Photographs.—Photographs attached at end of report.

Design Report

"Type of Elimination.—It is possible to construct either an overhead or : subway elimination.

"The overhead type is recommended as the most economical solution.

Estimated total cost overhead, including property damage....... $133,00

Estimated total cost subway, including property damage......... 165,00

"While a subway is feasible, the drainage is difficult, requiring an expensiv sewer about 2800′ long estimated to cost approximately $23,000

"The abutting property owners prefer a subway, but all this property i residential, of low valuation. Considering the fact that residential propert of this kind next to a railroad has little value and that the total cost of th overhead is materially less than for a subway, it seems reasonable to adop the overhead type of elimination for this project.

"Fill approaches on the west are obviously the proper designs. Fil approach with a short retaining wall on the east is adopted, as it saves fror $25,000 to $30,000 over a trestle-approach design, allowing for a sligh increase in property damage for three owners. This large saving appar ently warrants the design, as the extra property damage is small. The fi approach is also more permanent than the trestle design.

"Location and Alignment. *Main Road.*—The existing road location an alignment is retained, as this is obviously the best solution, considering th village property and the importance of the highway (main Rochester-Buffal road).

"The skew angle of crossing could be slightly reduced by reverse approach alignment, but the small saving in cost (approximately $13,000) would not warrant the adoption of the crooked approach alignment with more danger and poorer appearance.

"*Corporation Line Approach Road.*—This road has a very small amount of travel. We have relocated 500′ of this highway to increase the safety of travel at the junction of this road with the main road.

"This relocation costs about $6000 less than the retention of the existing location with a high approach fill and at the same time increases the safety of the layout.

"**Grades.**—Six per cent maximum approach grades are recommended on account of reduced property damage, 5 % is the prevailing maximum on this route, but 6 % will not materially increase danger, considering that the approach alignment is excellent.

"**Sight Distance.**—Vertical curves designed to give a 350′ minimum sight distance on the main road.

"This is the minimum desirable distance for a road of this importance.

"Minimum sight distance at intersection of main road with corporation line approach road, 350′.

"**Drainage.**—Simple—no comment necessary.

"**Roadway Section.**—Thirty-five feet top width of fill, including side path for pedestrians on north side. Width of fill can be increased at any time to handle future traffic growth.

"Provision for pedestrians adds about $8000 to the cost of this elimination, but is most certainly desirable, considering future growth of Churchville Village and the heavy volume of highway traffic.

"**Pavement.**—Reinforced cement concrete 20′ wide flared to 24′ at bridge is used, as this is the main Rochester-Buffalo road.

"Sixteen feet bituminous macadam is used on the corporation line approach road. The present road is a 10′ water-bound macadam.

"**Temporary Side Road.**—A temporary side road with a 24-hr. watchman at the crossing will be necessary, as there is no chance for a good normal road detour.

"As the volume of traffic is heavy, this side road must be a good job; we have figured on 16′ width of gravel 9″ deep with a grading width of 22′ safe to drive on.

"The amount for the watchman is figured as 16 hr. per day over and above the present protection of 8 hr.

"**Transmission Line.**—The transmission line of the Niagara, Lockport & Ontario Power Co. will have to be raised. The estimated cost of this work is based on an estimate furnished by the Buffalo office of this company ($5000).

"**Bridge.**—Solid floor-plate girder main span with reinforced-concrete trestle approaches to eliminate solid abutments, pedestal and column supports; 24′ roadway + 5′ sidewalk; H-20 loading; 22′ vertical railway clearance; 10′ side clearance (outer rail to pedestal). Making allowance for 40 years growth in traffic volume would probably justify a 30 ft. Roadway.

"The use of this type of bridge reduces the cost below that required for the solid abutment type about $12,000, including the reduction in fill and pavement items.

"The road profile grade line is based on a 3.5′ depth of floor system for the main span bridge, which is the usual depth used by the New York Central bridge designers.

"A reduction in floor depth to 3.0′ would reduce the cost of the fill approaches approximately $1500. We recommend a 3.0′ depth of floor system as being an economical design, considering the total cost of bridge and approaches. (See page 206 for discussion of floor depths.)

"**Detail Estimate.**—A detail estimate of cost is attached.

"**General Procedure.**—I recommend a physical division of the work, as we can get the approach work done considerably cheaper than the New York Central Railroad, whose bridge contractors are not familiar with or well equipped for road work.

New York Central Ry. Bridge and watchman at crossing.
State of New York. Approaches including temporary side road.
Niagara, Lockport & Ontario Power Co. Transmission Line.

(*Signed*)
Grade Crossing Engineer."

PRELIMINARY REPORT ON THE PROPOSED PITTSFORD-PALMYRA GRADE-CROSSING ELIMINATION (AUBURN BRANCH NEW YORK CENTRAL RY.) STAS. 0 TO 12 OF ROAD 766, ILLUSTRATING ECONOMIC COMPARISON OF DIFFERENT GRADE LAYOUTS

"**Summarized Recommendations.**—We recommend a highway under-crossing at an estimated cost of between \$85,000 to \$100,000. This estimate is based on raising the railroad tracks 1½ to 3′ and using a solid-floor single track through girder railroad bridge, E-60 loading, a clearance of 14′ from the bottom of the bridge to crown of road, a 26′ right-angle clearance between bridge abutments, a 5% maximum highway approach grade on straight alignment, necessary cleaning out and deepening of creek channel with enlarged and rebuilt culverts to provide proper drainage, and a reinforced-cement-concrete pavement 7¾″ average thickness, 18′ normal width except under the bridge, where the width is 26′ to give an impervious surface between abutments.

"The decision in regard to the amount of track raise is based on drainage difficulty and the comparative total cost of this project as affected by different track raises. The following tabulation of comparative costs indicates that a 1½ to 2′ track raise seems to be a reasonable solution and we have therefore made the rough layout and preliminary design on this basis. This plan can be easily modified to conform with the ruling of the Public Service Commission, but we do not advise lowering the road grade below the elevations shown on the preliminary plan dated June 21, 1923, on account of general drainage conditions.

"On account of the heavy railroad grade to the south, it is possible that the railroad may desire to make a material raise in track grade at this crossing. However, there seems little justification for state cooperation in the cost of track raise of over 2 to 3′.

"We have recommended straight highway alignment on the score of safety. The cost, including loss of money in motor operation due to extra distance, could probably be reduced about \$35,000 by the use of three reverse 10° curves, but this would add as much danger due to poor highway alignment as now exists on account of the grade crossing. An elimination based on poor highway alignment is a waste of money.

"The following detail report gives additional data in regard to the necessity for this elimination and discusses the minor features of design.

Submitted,

Assistant Engineer."

For Report on Relocation Eliminations see page 775.

Quick-estimating Data.—The following graphs and tabulations are useful for preliminary estimates in connection with the selection of the most suitable general layouts and in estimating the cost of large programs. All the data given have been used for these purposes by the author in western New York and have been found to agree with final contract plans within from 2 to 10%.

(See page 648.)

REPORT ON ELIMINATION RAILROAD 766. APPROXIMATE TOTAL COST ESTIMATES
(As affected by track raises)

Items	Estimated costs					
	No raise	1′ track raise	2′ track raise	3′ track raise	4′ track raise	5′ track raise
Steel bridge superstructure, E-60	$27,000	$27,000	$27,000	$27,000	$27,000	$27,000
Bridge abutments	24,000	24,000	24,000	24,000	24,000	24,000
Temporary track protection	9,000	9,000	9,000	9,000	9,000	9,000
Raising track	......	1,300	3,600	6,200	9,100	12,000
Drainage	9,200	8,500	7,700	7,400	7,000	6,800
Highway and bridge excavation	16,000	14,500	13,000	11,500	10,000	8,500
Highway pavement (18′)	9,000	9,000	9,000	9,000	9,000	9,000
Totals	$94,200	$93,300	$93,300	$94,100	$95,100	$96,300

INDEX OF QUICK-ESTIMATING DATA

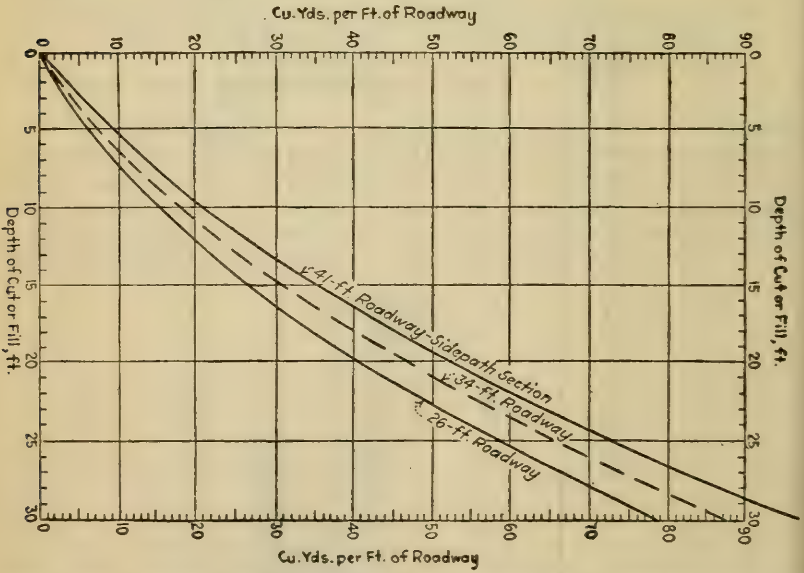
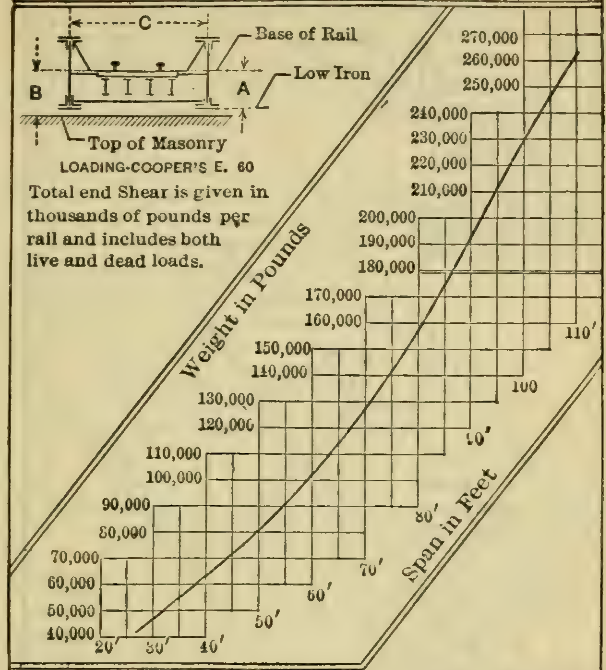


FIG. 208.—Graph for estimating road approach earthwork grade crossing eliminations.

THROUGH PLATE GIRDER SPANS, STRINGER FLOOR.
WEIGHTS, DIMENSIONS, ETC.



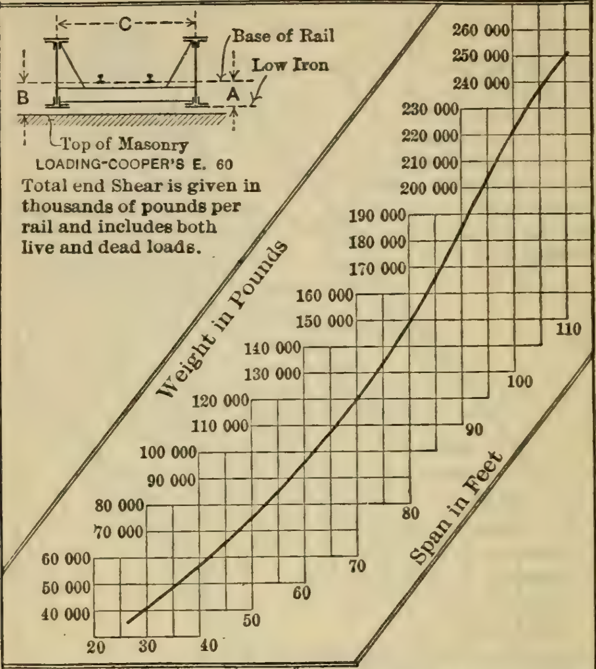
Span	Total End Sh.	A	B	C
30 Ft.	108.7	3'3"	3'3"	15'6"
35 "	121 0	3'3½"	3'3½"	16'6"
40 "	133.2	"	"	17'6"
45 "	144.7	"	"	"
50 "	156.0	"	"	"
55 "	167.5	3'4"	3'11"	"
60 "	176 3	"	"	"
65 "	191.1	3'4½"	"	"
70 "	204.7	"	"	"
75 "	220.4	"	5'0"	"
80 "	232.8	"	"	"
85 "	248.6	"	"	"
90 "	262.3	3'5"	"	"
95 "	277.4	"	"	"
100 "	291.2	3'6"	"	"
110 "	319 6	"	"	"

Erector's Note.
W = Total weight of one single track span with two light girders.

Span	Weight of one light girder.	Weight of one heavy girder.	Weight of one floor system.
30' to 50'	.24 W	.42 W	.52 W
55' to 80'	.25 W	.46 W	.50 W
85' to 110'	.28 W	.51 W	.44 W

FIG. 209A.—Open floor bridge.

THROUGH PLATE GIRDER SPANS, I-BEAM FLOOR WEIGHTS, DIMENSIONS, ETC.



Span	Total End Sh.	A	B	C
30 ft.	106.2	2'2"	2'2"	15'0"
35 "	117.1	"	"	16-0
40 "	128.7	"	"	17-0
45 "	141.1	2-2½	2-2½	17-6
50 "	152.2	"	"	"
55 "	162.1	2-3	2-9	"
60 "	173.2	"	"	"
65 "	186.2	"	"	"
70 "	199.3	2-3½	3-9	"
75 "	212.5	"	3-10½	"
80 "	226.4	"	"	"
85 "	240.5	"	"	"
90 "	257.4	"	"	"
95 "	268.7	"	"	"
100 "	284.0	2-4	"	"
110 "	306.0	2-4½	"	"

Erector's Note:
W = Total weight of one single track span with two light girders.

Span	Weight of one light girder	Weight of one heavy girder	Weight of one floor system
30' to 50'	.22 W	.39 W	.56 W
55' " 80'	.27 W	.48 W	.47 W
85' " 110'	.31 W	.57 W	.38 W

FIG. 209*B*.—Open floor bridge.

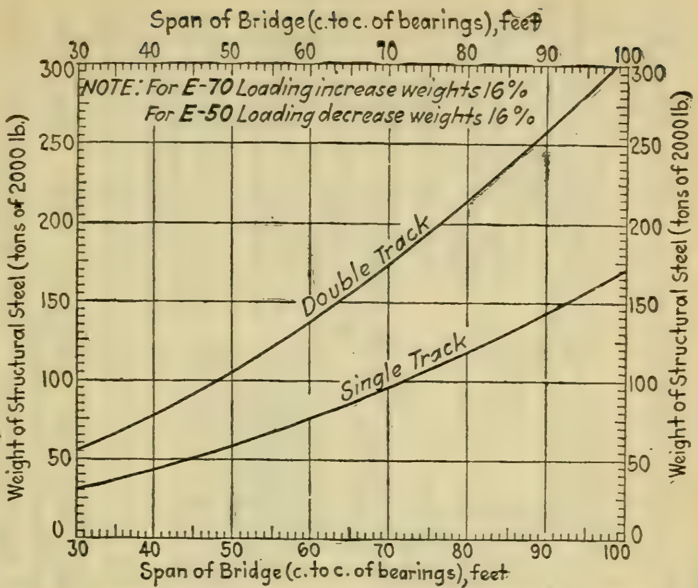


FIG. 210.—Approximate weight structural steel through girder—solid floor Ry. bridges Coopers E-60 loading.

Note: For E-70 loading increase weights 16 %
For E-50 loading decrease weights 16 %.

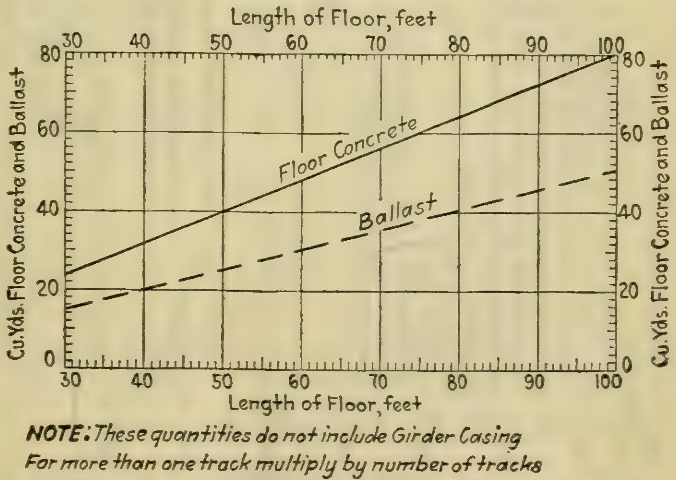
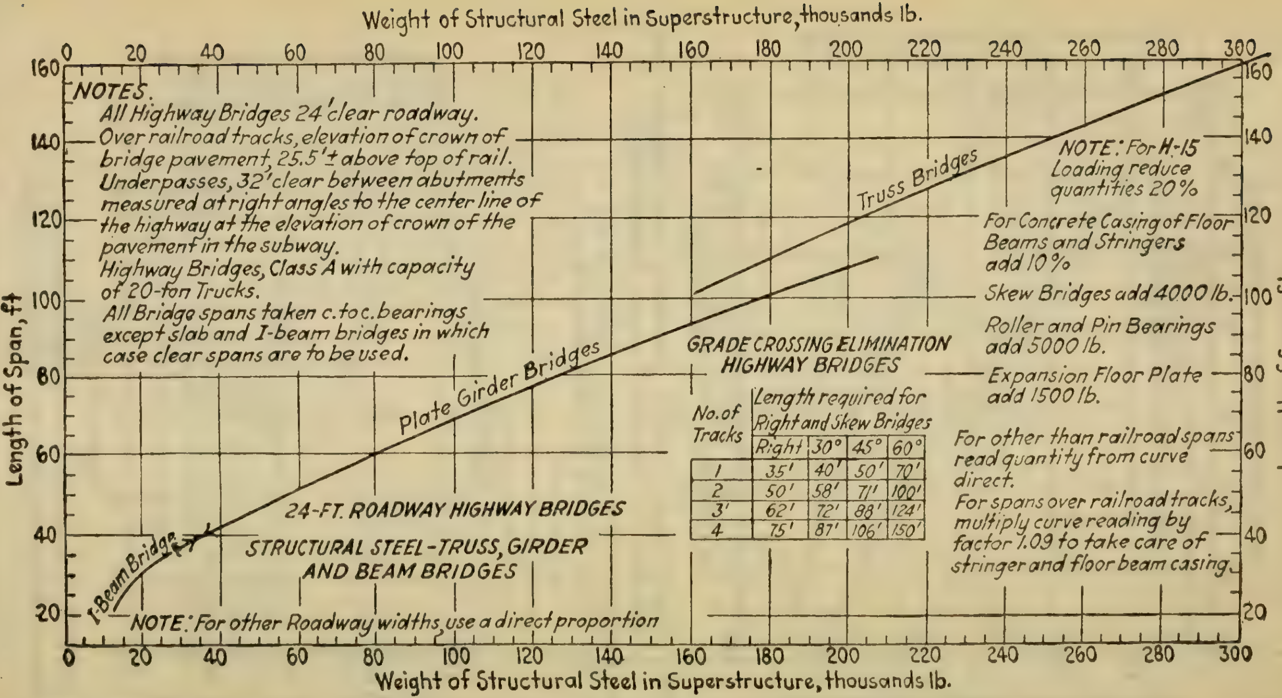
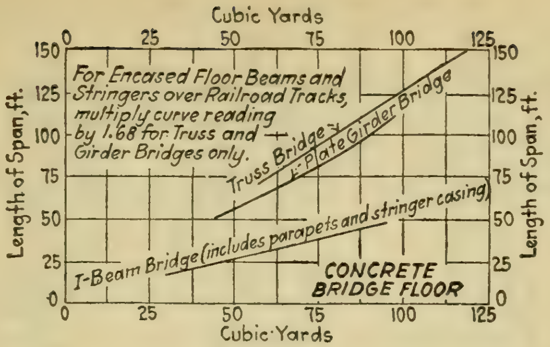


FIG. 211.—Approx. amount of floor concrete and ballast single track railroad girder bridges E-60 loading.



No. of Tracks	Length required for Right and Skew Bridges			
	Right	30°	45°	60°
1	35'	40'	50'	70'
2	50'	58'	71'	100'
3'	62'	72'	88'	124'
4	75'	87'	106'	150'

FIG. 212.—Weights of structural steel in H-20 solid floor highway bridges. (New York Standards, 1926.) (24 ft. width of roadway.)



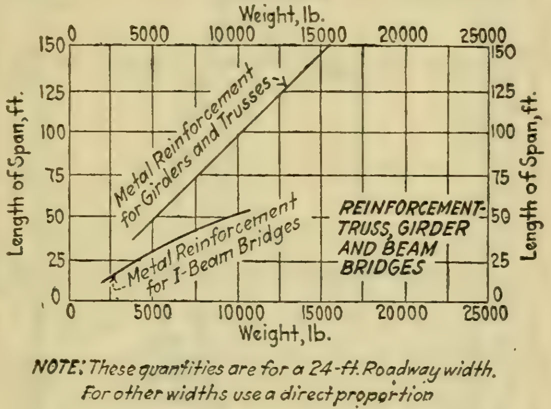


FIG. 213.—Amounts of concrete in highway bridge floors H-20 loading 24 ft. roadway.

FIG. 214.—Amounts of reinforcing steel in highway bridge floors H-20 loading 24 ft. roadway.

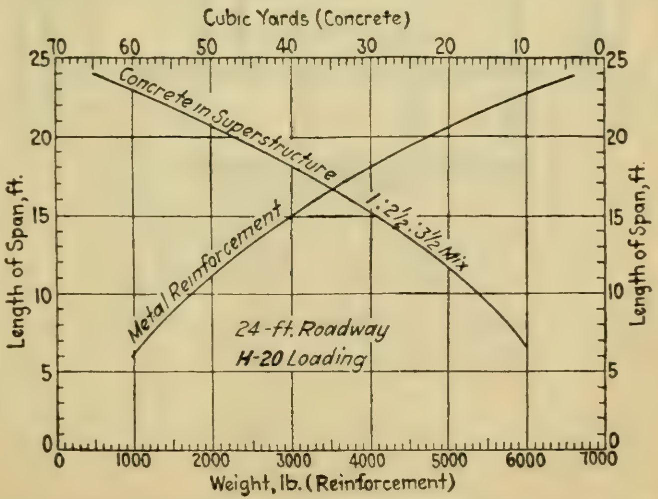


FIG. 215.—Amounts of concrete and reinforcement concrete slab superstructures. Highway bridges H-20 loading 24 ft. roadway.

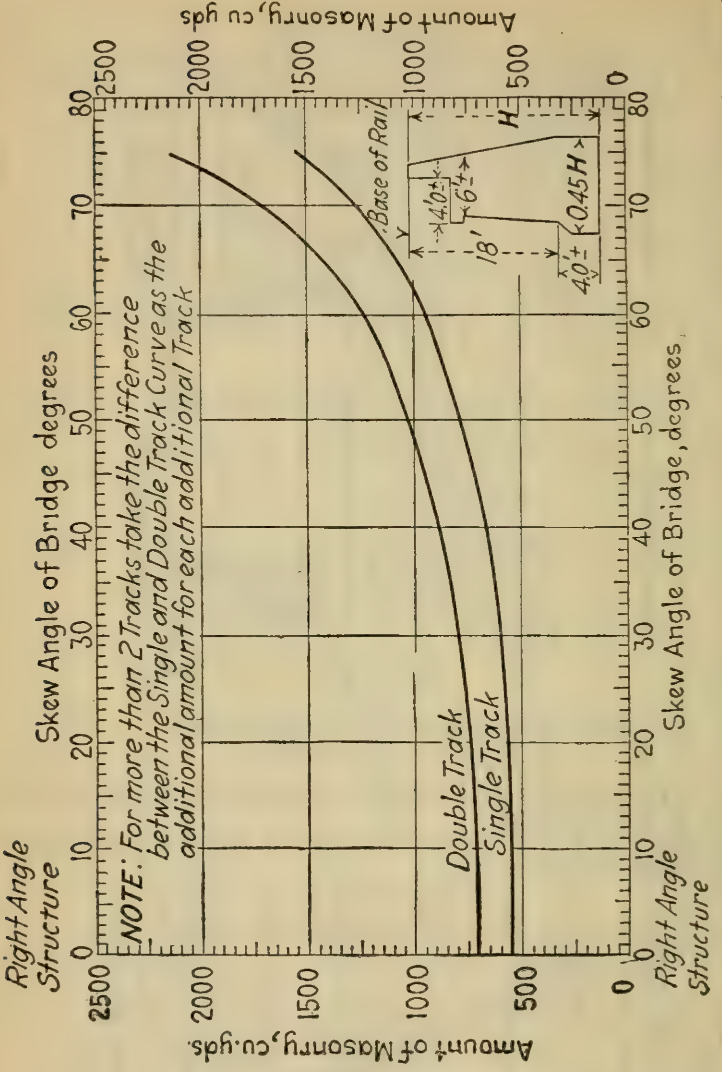


FIG. 216.—Approx. quantities for 2 abutments and 4 wings railroad bridges for usual highway underclearance of 14.0′ bottom of bridge to crown of road, which is equivalent to 18.0′ from base of rail to crown of roadway pavement.

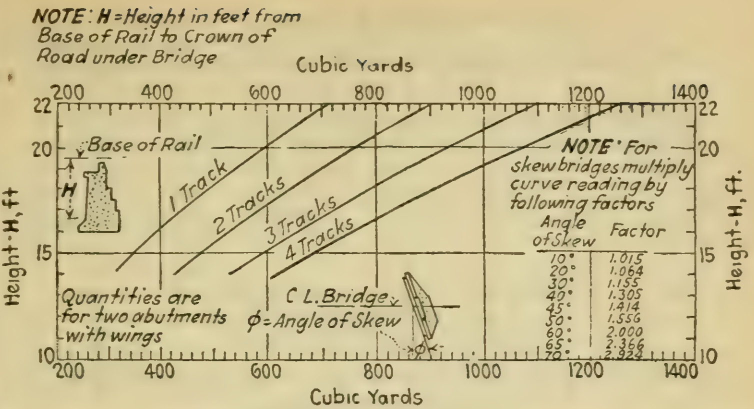
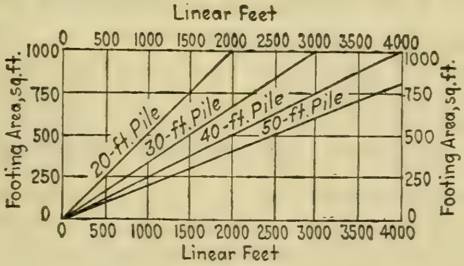


FIG. 216A.—Concrete in railroad bridge abutments N. Y. State 1926 standards.



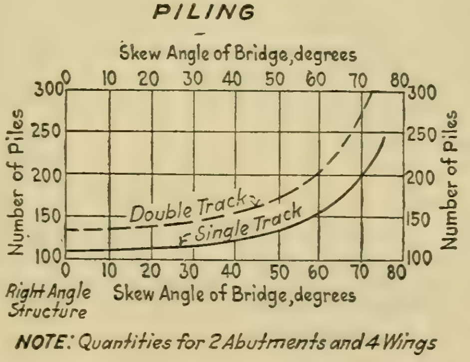


FIG. 217.—Amount of piling under railroad bridge abutments.

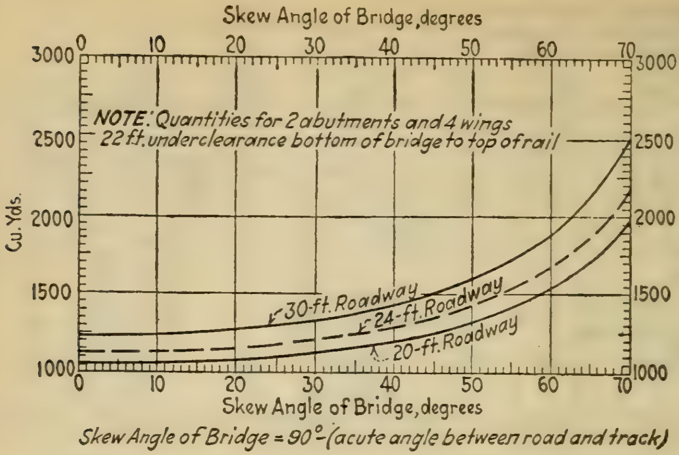


FIG. 218.—Quantities for highway bridge abutments overhead bridge eliminations.

PEDESTAL AND TRESTLE APPROACH DATA[1]

"Economical trestle span between bents:

16′ bent spacing (24′ roadway)	$130 cost per linear foot
20′ bent spacing (24′ roadway)	125 cost per linear foot
25′ bent spacing (24′ roadway)	135 cost per linear foot
30′ bent spacing (24′ roadway)	150 cost per linear foot

"NOTE.—Add 10 % for skew. Add $20 per foot for sidewalk.

"Unit prices:

1: 2½: 5 concrete foundations	$18 per cubic yard
1: 2: 4 reinforced concrete	30 per cubic yard
Reinforcing steel	6 cts. per pound
Piles	1.20 per foot

Per cent, reinforced pedestals, 0.3 (40 lb. per cubic yard).
Per cent, reinforced columns, 1.2 (160 lb. per cubic yard).
Per cent, reinforced beams and floors, 0.7 (100 lb. per cubic yard).
Per cent, reinforced T-beam construction, 1.4 (200 lb. per cubic yard).

"Modulus of rupture reinforced concrete (design stress), 400 lb.

"Allowable foundation pressures:

Ordinary clay and sand mixed	2 tons per square foot
Soft clay	1 ton per square foot
Stiff clay	4 tons per square foot
Gravel and sand	4 tons per square foot
Rock (poor)	5 tons per square foot
Rock (good)	25 tons per square foot

"Piles, 17-ton maximum per pile.
"Concrete weighs 4000 lb. per cubic yard.
"Conservative design, H-20 loading."

[1] Compiled by W. G. Harger, 1924.

Overhead Highway Bridge Pedestal Supports

"Quantities for four pedestals.
"Foundations (Ordinary soils 2 tons per square foot).
"Piles if used (17 tons per pile maximum).

50′ main span	48 piles minimum
75′ main span	56 piles minimum
100′ main span	68 piles minimum

"Four foundations 1:2½:5 concrete at $18 per cubic yard, steel reinforcement, quantities as follows:

	Concrete, cubic yards	Steel, pounds
50′ main span	50	2000
75′ main span	62	3000
100′ main span	74	4000

"Four columns 1:2:4 concrete at $25 per cubic yard (20′ seat to top of foundation, quantities as follows:

	Concrete, cubic yards	Steel, pounds
50′ main span	80	3200
75′ main span	86	3400
100′ main span	92	3700

"Load on each pedestal footing:

50′ main span	250,000 + 160,000 = 410,000
75′ main span	310,000 + 170,000 = 480,000
100′ main span	380,000 + 180,000 = 560,000

"Bottom dimensions of pedestal footings (ordinary soils):

	Area, square feet	Dimensions, feet
50′ main span	100	10 by 10
75′ main span	120	11 by 11
100′ main span	140	12 by 12

Superstructure (H-20 Loading)

(Quantities per foot of length, using 24′ roadway)

"Slab type (24′ roadway) as follows:

	Concrete, cubic yards	Steel reinforcement, pounds
16′ span between bents	1.67	168
20′ span between bents	2.05	202
25′ span between bents	2.42	250
Stiffener braces	0.20	20

"Reinforced concrete, stringer type (24′ roadway) as follows:

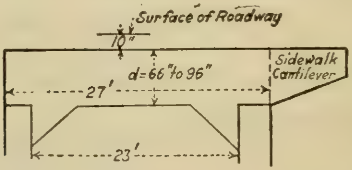
	Concrete, cubic yards	Steel reinforcement, pounds
16′ span between bents	1.89	380
20′ span between bents	2.08	420
25′ span between bents	2.44	500
30′ span between bents	2.89	580
Stiffener braces	0.1	20

"Six stringers spaced 5′ 06″.
"Ten-inch floor slab, stringers as follows:

16′ bents, 12″ wide, 42″ deep
20′ bents, 15″ wide, 42″ deep
25′ bents, 18″ wide, 48″ deep
30′ bents, 24″ wide, 48″ deep

"Note.—Where sidewalk is used add 15 % to above quantities. For H-15 loading reduce quantities 20 %.

Two Post Bents (Cross-beams and Braces)



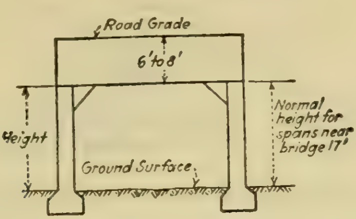
Two-span bents	Concrete, cubic yards	Steel, pounds
16′ span between bents (24 by 78″)	9.7	1350
20′ span between bents (24 by 84″)	10.5	1450
25′ span between bents (30 by 90″)	13.0	1950
30′ span between bents (30 by 96″)	14.0	2100

End bents	Concrete, cubic yards	Steel, pounds
16′ span (24 by 66″)	8.5	1150
20′ span (24 by 72″)	9.0	1250
25′ span (30 by 72″)	10.5	1600
30′ span (30 by 84″)	12.5	1850

"Notes.—The quantities given (concrete) deduct stringers, that is stringers and floor slab are computed by multiplying quantities by full length of approaches.
"If sidewalk is used add 15% to these figures. For H-15 loading reduce quantities 20%.

Two Post Bents

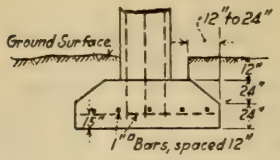
(Quantities for two posts per foot height between bottom of cross-beam and top of spread foundations)



Two-span bents	Concrete, cubic yards	Steel, pounds
16′ span (24 by 24″)	0.296	47
20′ span (24 by 24″)	0.296	47
25′ span (24 by 30″)	0.370	60
30′ span (24 by 30″)	0.370	60

End bents	Concrete, cubic yards	Steel, pounds
16′ span (24 by 24″)	0.296	47
20′ span (24 by 24″)	0.296	47
25′ span (24 by 30″)	0.370	60
30′ span (24 by 30″)	0.370	60

Two Post Bents (24′ Roadway)
Foundations



"Load on each footing.

	Two-span bents, pounds	End bents, pounds
16′ span	160,000	16′ span 125,000
20′ span	190,000	20′ span 145,000
25′ span	240,000	25′ span 180,000
30′ span	310,000	30′ span 225,000
"Piles if used for each column footing (20 to 30′ long):		
16′ span	5 piles	4 piles
20′ span	6 piles	5 piles
25′ span	7 piles	6 piles
30′ span	9 piles	7 piles

"Quantities for two-column footings (ordinary foundation soil, 2 tons p square foot):

	Two-span bents		End bents	
	Concrete, cubic yards	Steel, pounds	Concrete, cubic yards	Steel, pounds
16′ span...........	9.2	470	8.0	430
20′ span...........	12.1	560	9.2	470
25′ span...........	15.4	670	12.1	560
30′ span...........	20.0	800	13.7	610

"Bottom dimensions, column footings:

	Two-span bents, area, square feet		End bents, area square feet	
16′ span.........................	40	6 by 6	30	5 by 6
20′ span.........................	50	7 by 7	35	6 by 6
25′ span.........................	60	8 by 8	45	7 by 7
30′ span.........................	80	9 by 9	55	7 by 8

UNIT PRICES BRIDGE AND GRADE-CROSSING WORK

Compiled, 1925, by W. G. Harger for Western New York Conditions

Item number	Item	Unit price
1	Clearing and grubbing	Special each case
2a	Earth excavation (borrow pit)	$ 0.70 per cubic yard
2b	Earth excavation roadway, common	0.90–1.50 per cubic yard
2c	Earth excavation foundations and culverts (dry)	2.00–2.50 per cubic yard
2d	Earth excavation foundations and culverts (wet)	4.00 per cubic yard
2e	Earth excavation slip scraper ditch work	0.75 per cubic yard
2f	Earth excavation sewers	Included in pipe price
2g	Backfill (abutments)	1.25 per cubic yard
3a	Rock excavation common roadway (shale)	2.00 per cubic yard
3aa	Rock excavation common roadway (hard)	2.50 per cubic yard
3b	Rock excavation in foundations (dry)	6.00 per cubic yard
3c	Rock excavation in foundations (wet)	8.00 per cubic yard
3d	Rock excavation removing old masonry	4.00 per cubic yard
5	Overhaul	0.007–0.01 per station yard
6	Sewer pipe	(See sewer diagrams)
7a	4″ underdrain	0.25 per linear foot
7b	6″ underdrain	0.35 per linear foot
10	Relaying old pipe	0.20 per linear foot
13a	12″ cast-iron pipe (medium weight)	3.50 per linear foot
13b	14″ cast-iron pipe (medium weight)	4.50 per linear foot
13c	16″ cast-iron pipe (medium weight)	5.70 per linear foot
13d	18″ cast-iron pipe (medium weight)	7.00 per linear foot
13e	20″ cast-iron pipe (medium weight)	8.50 per linear foot
13f	24″ cast-iron pipe (medium weight)	10.00 per linear foot
13g	30″ cast-iron pipe (medium weight)	15.00 per linear foot
13h	36″ cast-iron pipe (medium weight)	20.00 per linear foot
	Pointing old masonry	0.05 per square foot
16	Rip-rap	2.50 per cubic yard
17	Piles	0.90–1.20 per linear foot
18	Timber and lumber	80.00 per thousand
19	Portland cement	3.20 per barrel
20a	1:2:4 concrete[1] (jack arch floor)	18.00 per cubic yard
20b	1:2:4 concrete[1] (formed floor)	20.00 per cubic yard
20c	1:2:4 concrete[1] (slabs)	20.00 per cubic yard
20d	1:2:4 concrete[1] (trestle designs)	25.00 per cubic yard
21a	1:2½:5 concrete[1] foundations	10.00 per cubic yard
21b	1:2½:5 concrete[1] abutments (large work)	14.00 per cubic yard
21c	1:2½:5 concrete[1] abutments and pedestals (small)	16.00 per cubic yard
22a	1:3:6 concrete[1] pipe jackets	10.00 per cubic yard
27	Concrete[1] curbing	25.00 per cubic yard
27a	Curb bar	0.30 per linear foot
28	Concrete gutter (cement incl.)	18.00 per cubic yard
29	Cobble gutter (cement joints)	1.25 per square yard
30	Metal reinforcement concrete pavement	0.035 per square foot
31	Bar reinforcement concrete pavement	0.05 per pound
32b	Structural steel	
	Truss bridges	0.075 per pound
	Plate girders	0.07 per pound
	Rolled stringers	0.06 per pound

[1] Concrete prices do not include cement.

UNIT PRICES—*Continued*

Item number	Item	Unit price
32*a*	Bar steel (in structures).............	$0.06 to $0.07 per pour
33	Miscellaneous iron and steel.........	0.10 per pound
33½	Corrugated iron for bridge floor jack arches..........................	0.20 per square foo
34	Wooden guide rail..................	0.75 per foot
35	Cable guide rail....................	1.25 per foot
36	Concrete guide posts................	3.25 each
37	2″ pipe railing......................	3.00 per foot
38	Preparing fine grade................	0.10 per square yar
39	Run-of-bank gravel foundation........	3.00 per cubic yard
41	Field or quarry-stone foundation.....	4.00 per cubic yard
42	Run-of-bank gravel bottom..........	3.50 per cubic yard
44	Broken-slag bottom.................	6.00 per cubic yard
45	Broken-stone bottom................	7.00 per cubic yard
46	Concrete foundation for pavement (cement not included).............	7.00 per cubic yard
47	Bituminous-macadam top (bitumen not included).....................	9.00 per cubic yard
51*c*	Concrete pavement (cement not included).........................	10.00 per cubic yard
54	Brick pavement*..................	3.50 per square yai
55	Stone-block pavement*............	5.50 per square yai
56	Trimming shoulders................	0.10 per linear foot of ro
61	Broken slag (loose)................	4.00 per cubic yarc
62	Screened gravel (loose).............	3.00–4.00 per cubic ya
63	Broken stone (loose)................	4.50 per cubic yarc
66	Bituminous material *A* (penetration)	0.15 per gallon
71	Bituminous material *T* (penetration)	0.17 per gallon
75	Maintaining traffic..................	0.20 per foot
76	Resetting wooden guide rail.........	0.50 per foot
	Waterproofing......................	0.10 per square foo

* Does not include concrete base.

Miscellaneous Items

Labor raising track................ $ 0.80 per linear foot per foot rais
Pile temporary track protection during construction of railway bridges 30.00 per foot per track.

Cost of Interurban Electric Track Work

Ballast, ties, poles and wiring...... $5 per ft. single track.
Steel rails........................... $1.50 per ft. single track.

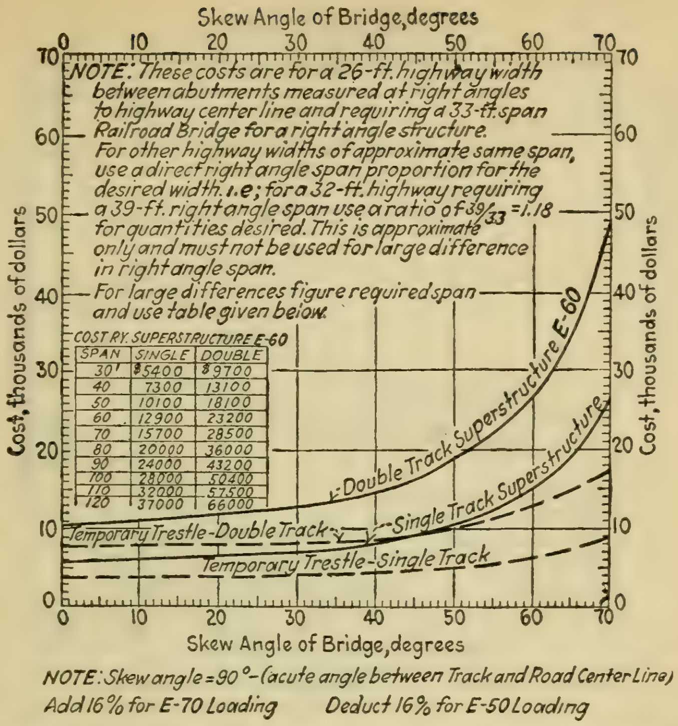


FIG. 219.—Cost diagrams railroad bridge superstructures.

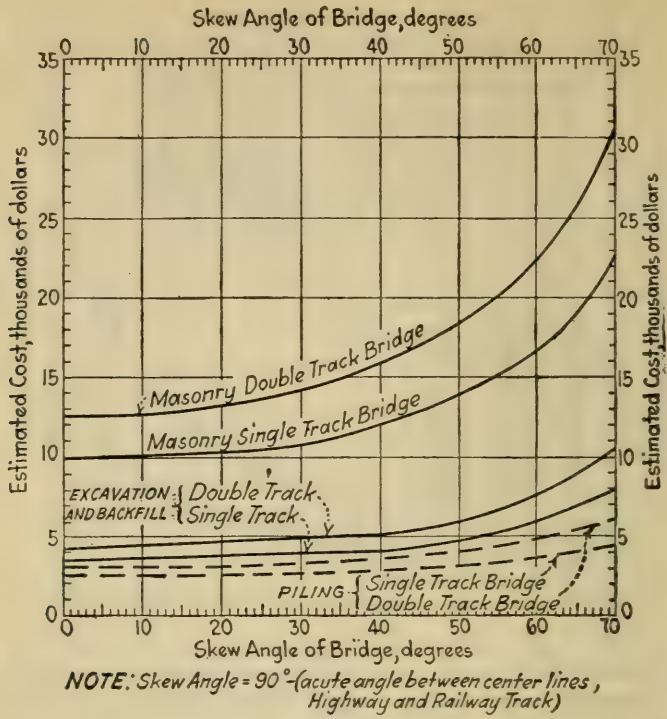
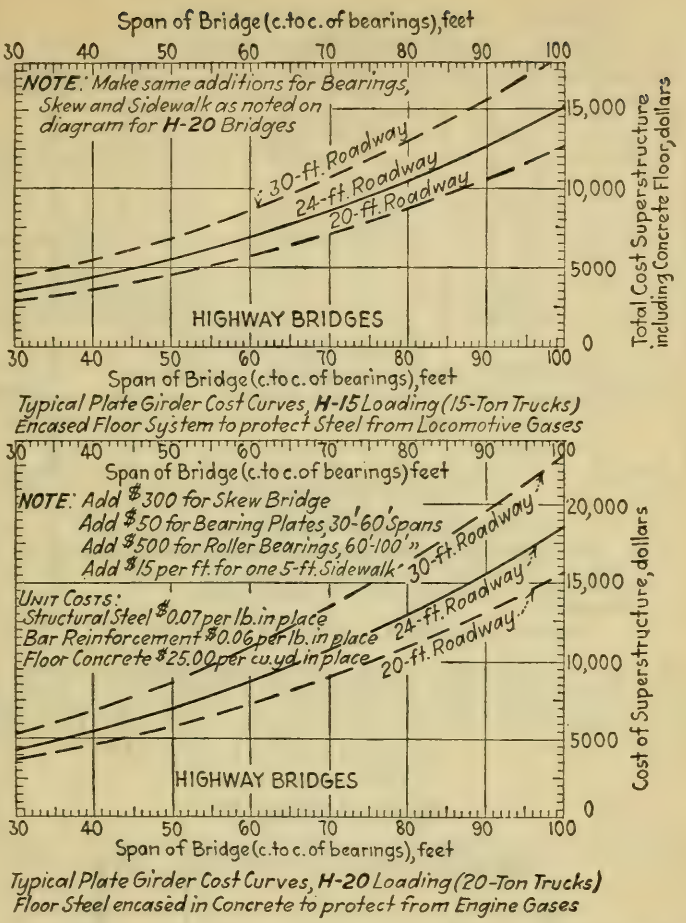


FIG. 220.—Approximate railroad bridge abutment costs. *Note:* All costs are for 2 abutments and 4 wings unit costs 19 conditions page 661.



IG. 221.—Typical cost curves plate girder highway bridge superstructures.

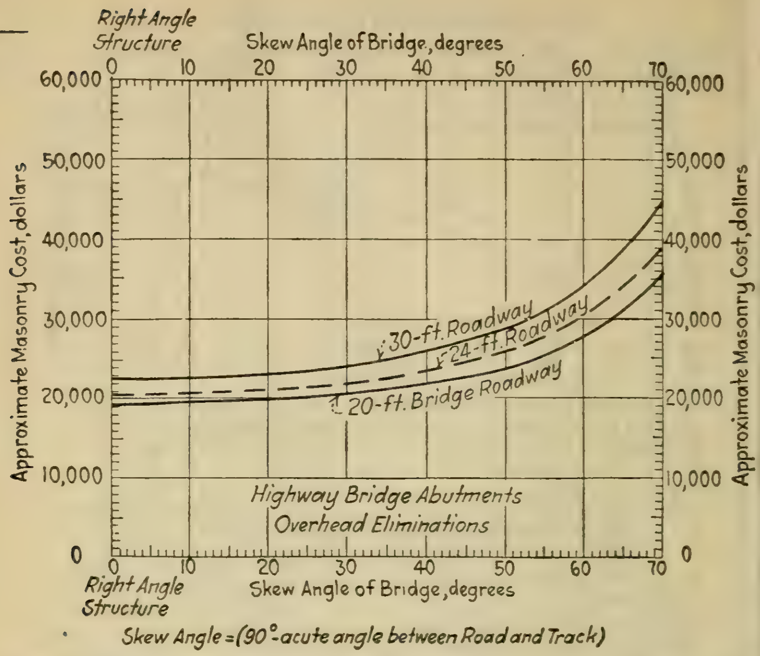


FIG. 222.—Approximate costs overhead highway bridge abu ments. Masonry costs 2 abutments and 4 wings 22 ft. undercle ance bottom of bridge to top of rail. Unit cost $18 per c. concrete. Figure exc. separately. Figure piles separately.

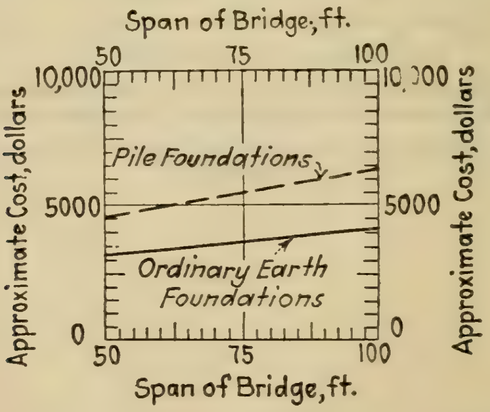
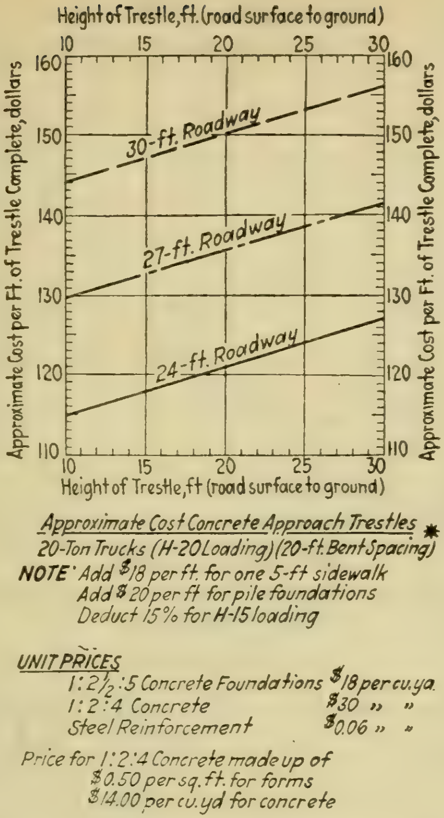


FIG. 223.—Approx. cost 4 pedestal supports. Overhead hig way bridge H-20 loading (24′ roadway). Used in connection wi trestle approaches. Excavation for 4 pedestals approx. $500.



G. 224.—Typical costs highway concrete trestle approaches grade crossing eliminations.

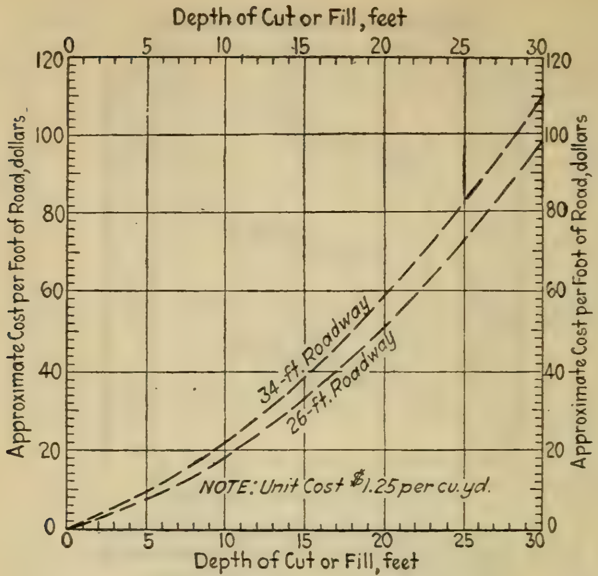


FIG. 225.—Typical costs highway earthwork on approaches gra crossing eliminations.

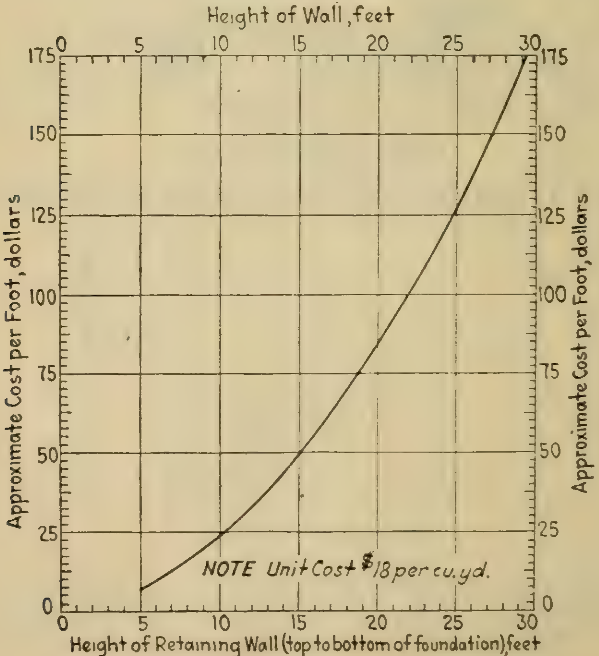


FIG. 226.—Typical cost curves gravity concrete retaining wal

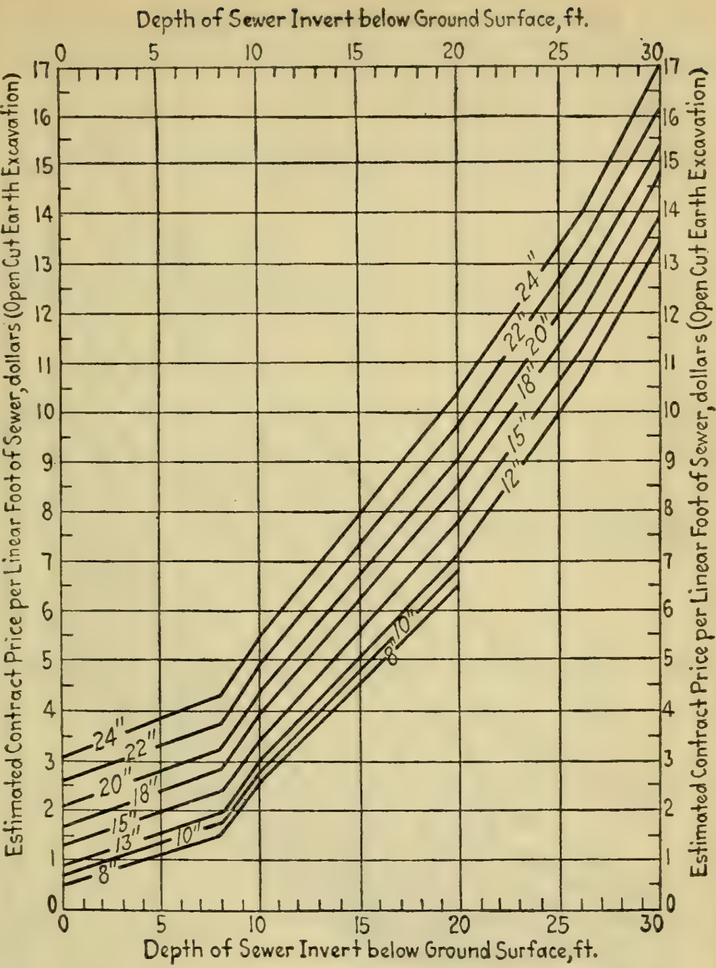


FIG. 227.—Typical cost of sewers including trench work as well as sewer proper (1922 cost conditions).

Graph No. 1 showing estimated contract costs per linear foot of vitrified pipe sewers at different depths.

NOTE.—These prices based on double strength pipe with cement joints.

If concrete jacket is used add item No. 55 to these prices.

If asphalt joints are used add item No. 19*A* to these prices.

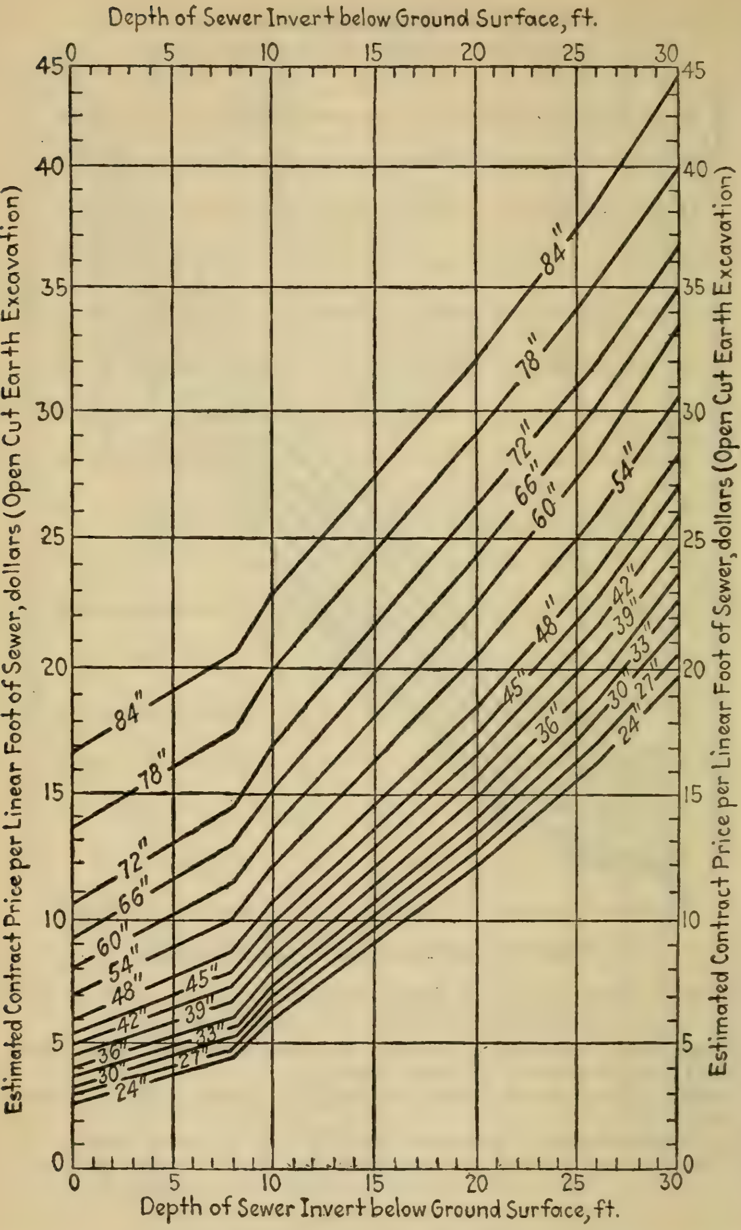


Fig. 227.—(*Continued.*)

Graph No. 2 showing estimated contract costs per linear foot of circular monolithic plain concrete sewers at different depths.

General Sewer Cost Data
City of Lima Ohio & Adjacent Territory
Prepared by
Fuller & McClintock
1921

TABLE SHOWING MINIMUM AMOUNT OF CLASS "B" CONCRETE JACKET PER LIN. FT. OF PIPE SEWER

Size pipe, diameter in inches	Number of c. y. concrete jacket per lin. ft. of sewer
8	0.030
10	0.035
12	0.04
15	0.05
18	0.09
20	0.10
22	0.11
24	0.12

TABLE SHOWING MININUM AMOUNT OF CLASS "B" CONCRETE CRADLE PER LIN. FT. OF PIPE SEWER

Size pipe, diameter in inches	Number of c. y. concrete cradle per lin. ft. of sewer
27	0.32
30	0.34
36	0.39
42	0.45
48	0.50
54	0.57
60	0.63

BASIC DATA 1921 SCALE OF PRICES

Common labor	$0.40 per hour
Hauling	0.30 per ton mile
Coal (f.o.b. cars Lima)	5.00 per ton
Cement (net bags returned)	2.50 per bbl.
Crushed stone (delivered on the work)	2.00 per c. y.
Concrete sand (f.o.b. cars Lima)	2.15 per ton
Sewer brick (f.o.b. cars Lima)	14.00 per M.
Timber for bracing	43.00 per M. ft. B.M.

Tile pipe

Size	Price
8	0.31
10	0.46
12	0.59
15	0.79
18	1.10
20	1.32
22	1.76
24	1.98

FIG. 227.—(*Continued.*)

FIG. 227.—(*Continued.*)

Item No.	List of items	Unit of measure	Estimated unit price
1–2½	Special concrete sewers	lin. ft.	Special
3–3A etc.	Special structures (junction chambers, etc.)	each	Special
(4–18)	Circular sewers 24″ to 84″ diam. (concrete or block)	lin. ft.	See Graph No. 2
4	24″ diameter circular sewers (open cut)	lin. ft.	See Graph No. 2
5	27″ diameter circular sewers	lin. ft.	See Graph No. 2
6	30″ diameter circular sewers	lin. ft.	See Graph No. 2
7	33″ diameter circular sewers	lin. ft.	See Graph No. 2
8	36″ diameter circular sewers	lin. ft.	See Graph No. 2
9	39″ diameter circular sewers	lin. ft.	See Graph No. 2
10	42″ diameter circular sewers	lin. ft.	See Graph No. 2
11	45″ diameter circular sewers	lin. ft.	See Graph No. 2
12	48″ diameter circular sewers	lin. ft.	See Graph No. 2
13	54″ diameter circular sewers	lin. ft.	See Graph No. 2
14	60″ diameter circular sewers	lin. ft.	See Graph No. 2
15	66″ diameter circular sewers	lin. ft.	See Graph No. 2
16	72″ diameter circular sewers	lin. ft.	See Graph No. 2
17	78″ diameter circular sewers	lin. ft.	See Graph No. 2
18	84″ diameter circular sewers	lin. ft.	See Graph No. 2
(19–26)	Vitrified pipe sewers (cement joints), open cut	lin. ft.	Graph No. 1
19	8″ vitrified pipe sewer in open cut	lin. ft.	
19A	Bituminous joints in 8″ pipe sewer, extra	per joint	0.15
20	10″ vitrified pipe sewer in open cut	lin. ft.	Graph No. 1
20A	Bituminous joints in 10″ pipe sewer, extra	per joint	0.20
21	12″ vitrified pipe sewer in open cut	lin. ft.	Graph No. 1
21A	Bituminous joints in 12″ pipe sewer, extra	per joint	0.25
22	15″ vitrified pipe sewer in open cut	lin. ft.	Graph No. 1
22A	Bituminous joints in 15″ pipe sewer, extra	per joint	0.30
23	18″ vitrified pipe sewer in open cut	lin. ft.	Graph No. 1
23A	Bituminous joints in 18″ pipe sewer, extra	per joint	0.40
24	20″ vitrified pipe sewer in open cut	lin. ft.	Graph No. 1
24A	Bituminous joints in 20″ pipe sewer, extra	per joint	0.50
25	22″ vitrified pipe sewer in open cut	lin. ft.	Graph No. 1
25A	Bituminous joints in 22″ pipe sewer, extra	per joint	0.70
26	24″ vitrified pipe sewer in open cut	lin. ft.	Graph No. 1

27	5″ and 6″ vit. pipe not otherwise provided for	per joint	0.90
28	8″ vit. pipe not otherwise provided for	lin. ft.	0.50
29	10″ vit. pipe not otherwise provided for	lin. ft.	0.60
30	12″ vit. pipe not otherwise provided for	lin. ft.	0.80
31	15″ vit. pipe not otherwise provided for	lin. ft.	1.00
32	18″ vit. pipe not otherwise provided for	lin. ft.	1.30
33	20″ vit. pipe not otherwise provided for	lin. ft.	1.70
34	22″ vit. pipe not otherwise provided for	lin. ft.	2.20
35	24″ vit. pipe not otherwise provided for	lin. ft.	2.60
36	5″ and 6″ vit. pipe specials	lin. ft.	3.10
37	8″ vit. pipe specials	each	1.20
38	10″ vit. pipe specials	each	1.50
39	12″ vit. pipe specials	each	1.70
40	15″ vit. pipe specials	each	2.00
41	18″ vit. pipe specials	each	2.80
42	20″ vit. pipe specials	each	3.60
43	22″ vit. pipe specials	each	4.60
44	24″ vit. pipe specials	each	5.50
45	6″ risers	each	7.00
46	Standard manhole	lin. ft.	2.40
47	Rock excavation	lin. ft.	10.00
48	Additional earth excavation in open cut (0′–10′ deep)	c. y.	6.00
49	Additional earth excavation in open cut (10′–15′ deep)	c. y.	1.20
50	Additional earth excavation in open cut (15′–20′ deep)	c. y.	2.70
51	Additional earth excavation in open cut (20′–25′ deep)	c. y.	3.00
52	Additional earth excavation in open cut (25′–30′ deep)	c. y.	3.30
53	Additional earth excavation in open cut (30′–35′ deep)	c. y.	3.70
54	Additional earth excavation in open cut tunnel	c. y.	4.00
54½	Extra allowance for required tunnel on vit. pipe sewer	c. y.	5.50
55	Class "B" concrete jackets around vit. pipe sewers	lin. ft.	1.00
56	Additional class "B" concrete	c. y.	11.00
57	Additional class "A" concrete	c. y.	12.00
58	Additional brick masonry not otherwise provided for	c. y.	15.00
59	Sheeting and timbering left in place	c. y.	35.00
60	Lumber and foundations	c. y.	
61	Piles	lin. ft.	2.00
62	Iron castings	lb.	0.08

FIG. 227.—(*Continued.*)

Item No.	List of items	Unit of measure	Estimated unit price
62–01	Lock manhole covers	each	100.00
63	Steel reinforcement	lb.	0.08
64	Metal mesh reinforcement	lb.	0.10
65	Cast iron pipe	ton	100.00
66	Cast iron pipe specials	ton	200.00
67	Cutting and removing macadam pavements	sq. yd.	0.15
68	Cutting and removing block pavements on macadam base	sq. yd.	0.50
69	Cutting and removing pavements having concrete base	sq. yd.	1.20
70	Relaying block pavements on 9″ macadam base	sq. yd.	2.80
71	Relaying block pavements on 9″ class "B" concrete	sq. yd.	3.50
72	New 6″ waterbound macadam	sq. yd.	1.20
73	New 9″ waterbound macadam	sq. yd.	2.00
74	New 9″ bituminous macadam	sq. yd.	2.50
75	New 3″ bituminous macadam on 9″ concrete base	sq. yd.	3.50
76	New brick pavement on 9″ concrete base	sq. yd.	5.00
77	New asphalt block pavement on 9″ concrete base	sq. yd.	5.50
78	New wood block pavement on 9″ concrete base	sq. yd.	6.00
79	New sheet asphalt pavement on 9″ concrete base	sq. yd.	4.50
80	New reinforced cement concrete pavement 9″ thick	sq. yd.	4.20
81	Special tamping	c. y.	1.00
82	Tamping up and relaying sidewalk	sq. ft.	0.25
83	Removing and resetting or rebuilding curb and gutter	lin. ft.	1.50
84	Catch basins for combined sewers (trapped)	each	70.00
85	Catch basins for separate storm sewers	each	50.00
86	Track protection	l. s.	Special
87	Maintaining existing flow of sewage	l. s.	Special
88	Care of existing structures	l. s.	Special
89	Loose stone for temporary road surface	c. y.	Special
90	Special items		
91			
92			
93 etc.			

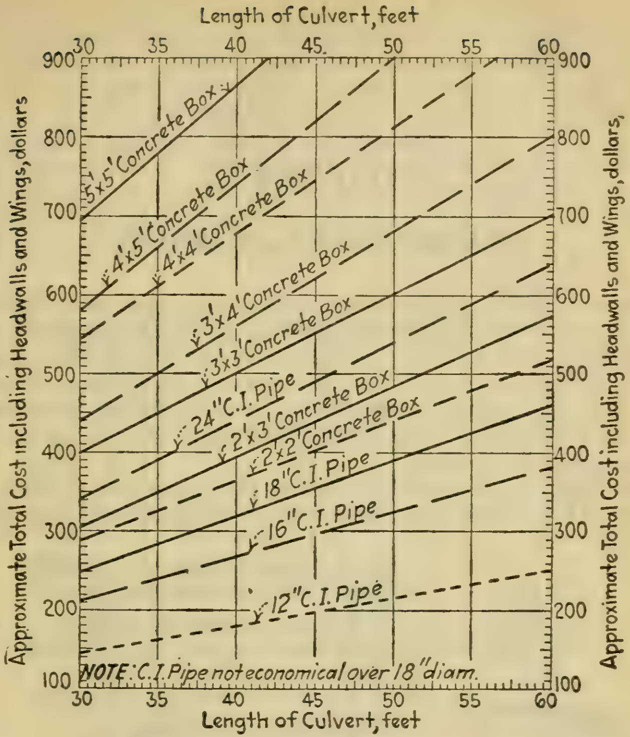


FIG. 228.—Approx. cost of culverts (exclusive of excavation) N. Y. State standards.

Note: Cast iron pipe not economical over 18″ dia.

CHAPTER X

MINOR POINTS OF DESIGN

For convenience of reference this chapter gives a few illustration of current practice in connection with incidental features of roac construction, such as guide rails, retaining walls, curbs, sidewalks cobble ditch protection, guide and danger signs, snow fences, etc These data are perhaps unnecessary but incidental information i useful in emergencies and gives the student some idea of curren practice in minor details.

Guard Rail.—The guard rail serves two purposes, to warn and t protect. If protection is essential at really dangerous points

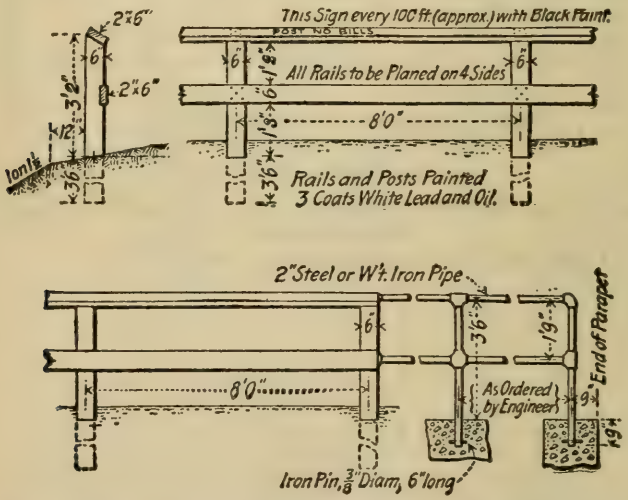


FIG. 229.—Wooden guide rail (New York State 1921). This typ is a warning rail only.

solid retaining wall is desirable. Most types of so-called guard rai serve more in the nature of a warning than as an actual protectioi Wooden structures require continual maintenance, and for th reason concrete posts, rail, and steel cables have been used on th score of reducing the necessity of continual repair. Figures 22 to 233 show usual types.

Retaining Walls.—In unusual cases, retaining walls are needed i road construction. Plain or reinforced-concrete walls are generall used, the selection depending on the relative cost. The plai

concrete wall is considered the best type for heights up to 12′; the reinforced cantilever form from 12 to 18′; and above 18′, the buttressed design. Standard practice for the plain and reinforced cantilever types page 682. The necessity for walls higher than 18′ is very rare. For the design of butressed walls the reader is referred to the standard works on reinforced concrete.

Retaining walls are usually built in monolithic sections of 20 to 25′ in length; expansion joints are provided between these sections. The expansion joints may consist simply of a plane of weakness between the sections, produced by allowing one section

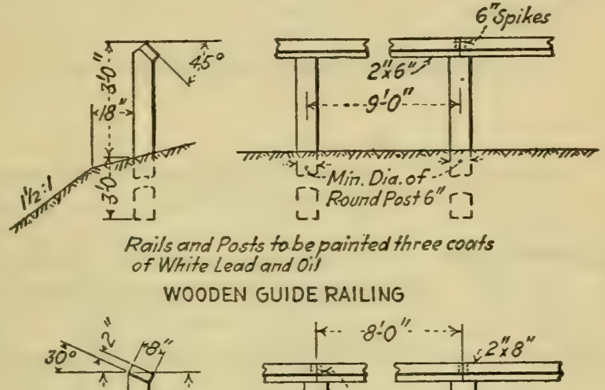
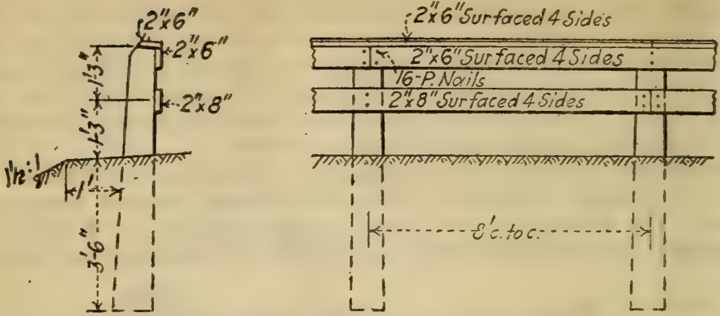


FIG. 229*A*.—Wooden guide rail U. S. Bureau Public Roads 1926.

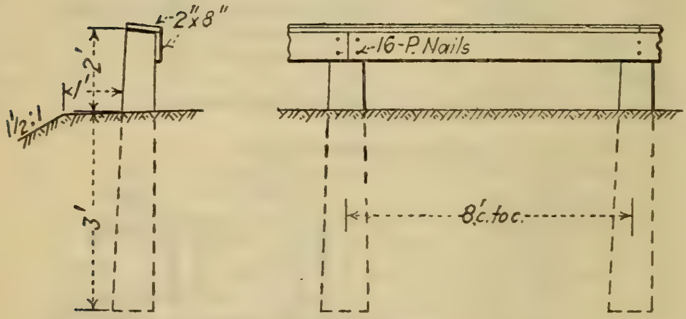
o set before building the adjacent wall, or it may be a key joint is shown in Fig. 236, and the plane of separation may be made more pronounced by coating the concrete with a thin layer of asphaltum or pitch (Fig. 236*A*).

Repointing Masonry and Refacing Old Walls.—Old masonry tructures can often be used complete or in part by repointing the oints; they should be cleaned out thoroughly with a chisel and lled flush with 1:1 Portland-cement mortar. The old joints

(text continued on page 681.)



WOODEN GUARD RAIL WITH HUB GUARD PLANK



Posts to be at least 6" in diam. or 6" square

Bark to be removed from posts and knots hewn flush, both round and square posts shall not be used on one contract

All Posts to be heavy brush-coated with creosote oil on bottom and sides up to a point 8" above ground level

All Joints to be painted before assembling and all exposed surfaces to have 3 coats of white lead and linseed oil, brushed in thoroughly

WOODEN HUB-HIGH GUARD RAIL

FIG. 229*B*.—Typical wooden hub guard. U. S. Bureau Public Roac
1926.

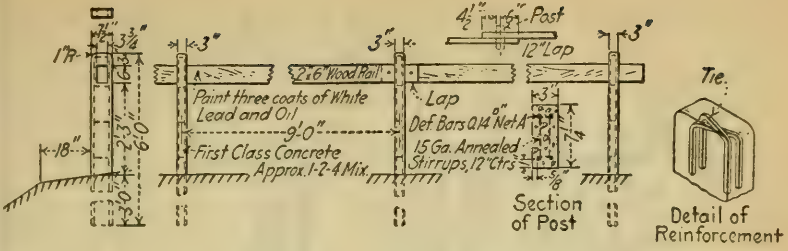


FIG. 230.—Concrete-wooden guide rail (New York State 1922). This type is a warning rail only.

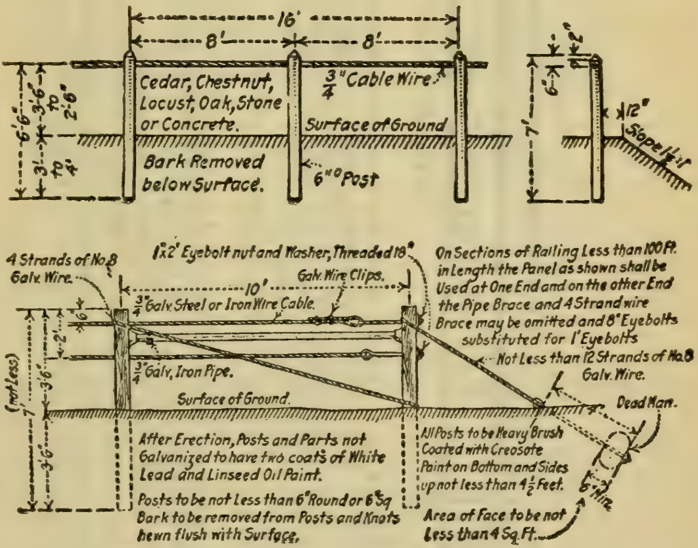


FIG. 231.—Cable guard rail (Penn. 1924). This type gives some protection.

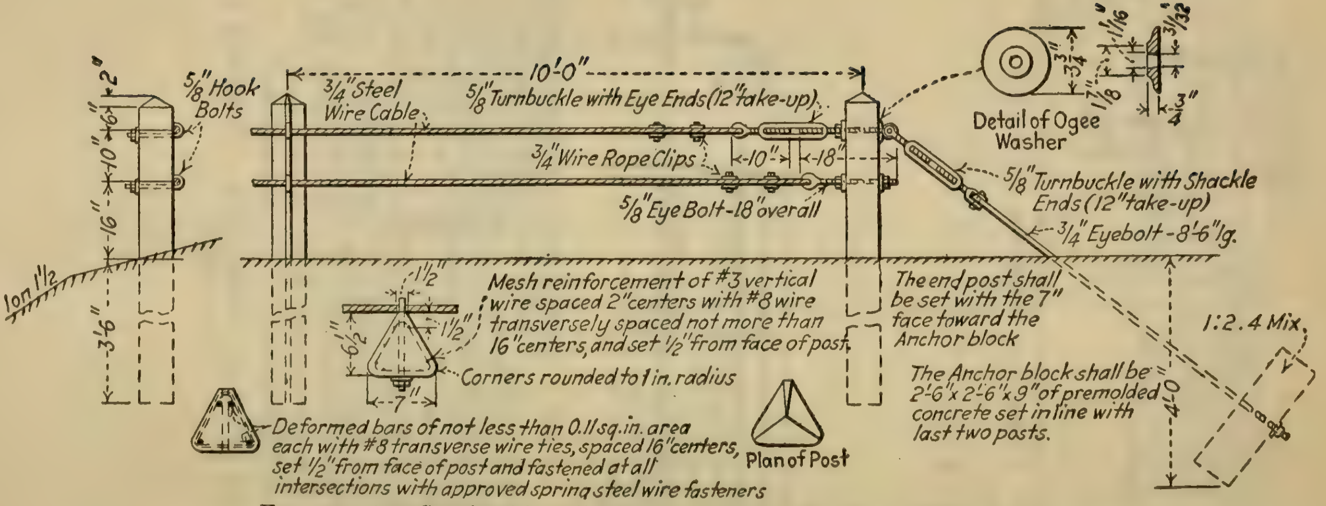


FIG. 232A.—Steel cable rail with concrete posts (N. Y. State 1927).

NOTE.—These same posts without cable are used as guide posts. They are a cheap and effective protection on straight alignment when spaced from 6 to 12 ft. between posts.

should be well cleaned out and hook dowels used as shown in Fig. 237. One dowel every 6 sq. ft. is good practice.

The concrete facing should be at least 12″ thick, have a good footing course, and be reinforced to prevent settlement and temperature cracks.

Toe Walls.—Toe walls are nothing more than low retaining walls or very substantial curbs. They are used in cuts on the outside of the gutters to prevent unstable side slopes from filling the gutters or heaving them out of shape by sliding pressure. Figure 238 gives a section of Eden Valley Hill near Buffalo, N. Y., where a clay quicksand cut was successfully protected in this manner.

Curbs.—Curbs are constructed of stone and of concrete (Fig. 239).

Stone Curbs.—The cuts given show the methods of setting; the size of curbstones for first-class work range from 16 to 22″ in depth, 5 to 6″ in thickness, and 3 to 5′ in length. For small villages, curbstone of 4″ width set in the simplest manner shown is satisfactory. The stones most used are granites, bluestones of

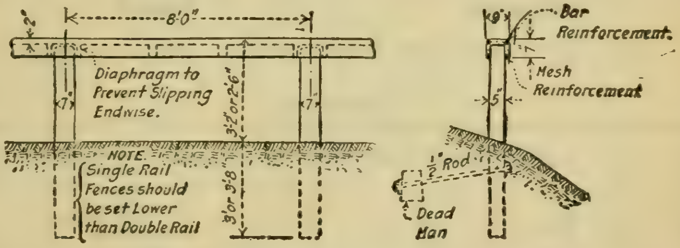


FIG. 233.—Typical reinforced concrete rail with post anchor blocks. This type gives some real protection as well as acting as a warning.

New York State, and the tougher sandstones, such as Medina, Berea, Kettle River, etc. The prices range widely, depending on the locality of the work.

Curb Radii.—A good radius for drives is 4′; for right-angle main-street intersections, 13′. For acute or obtuse angles 10 to 20′. Figure 240 shows a satisfatory sidewalk corner used in Rochester, N. Y. Where the street width and sidewalk layout permit a longer curb radius without inconvenience to pedestrians, the present tendency is to increase the curb radius to 25′. This permits the ordinary car to make the turn easily without swinging out from the curb traffic lane. This applies mainly to side streets intersecting with congested main streets.

Cobble Gutters, Brick Gutters, Ditch Linings, Etc.—Cobble gutters are used to protect the ditches from wash on steep grades and at entrances to intersecting roads where there is not sufficient headroom for a culvert, also at the entrances to private property where the grade line of the ditch might be badly cut by vehicles. Where cobblestones are not available, ordinary building brick may be used, or No. 4 crushed stone as shown in Fig. 241.

(text continued on page 687.)

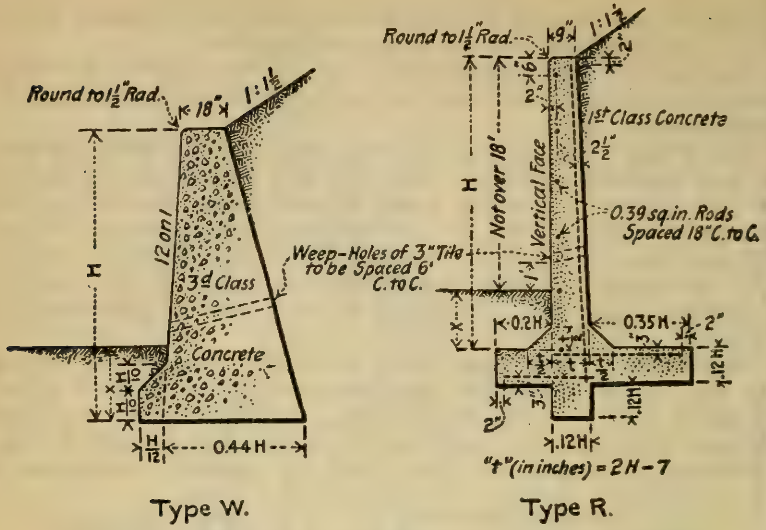


FIG. 234.—New York State standard retaining walls.

TABLE 116

H	Reinforcing Steel Bars of Deformed Section								
	Stem[1]			Heel			Toe		
	Net Area	Spacing C–C	Length	Net Area	Spacing C–C	Length	Net Area	Spacing C–C	Length
11′	0.601	6¼″	12′–2 ″	0.442	7½″	4′–11½″	0.442	9½″	3′–3½″
12′	0.601	5½″	13′–3½″	0.442	6¼″	5′–5½″	0.442	8¼″	3 –8″
13′	0.601	5″	14′–5 ″	0.442	5¼″	6′–0″	0.442	7¼″	4′–0½″
14′	0.601	4½″	15′–6½″	0.601	6¼″	6′–6″	0.601	8½″	4′–4½″
15′	0.601	4″	16′–8 ″	0.601	5⅜″	7′–0″	0.601	7⅜″	4′–9″
16′	0.994	6″	17′–9 ″	0.601	4¾″	7′–6½″	0.601	6½″	5′–1½″
17′	0.994	5½″	18′–10½″	0.785	5½″	8′–0½″	0.785	7⅝″	5′–6″
18′	0.994	5″	20′–0 ″	0.785	4⅞″	8′–7″	0.785	6⅞″	5′–10½′
19′	0.994	4½″	21′–1½″	0.785	4⅜″	9′–1″	0.785	6¼″	6′–2½″
20′	0.994	4⅛″	22′–3 ″	0.785	4 ″	9′–7″	0.785	5¾″	6′–7″

[1] In each set of 3 bars in stem, first bar which is of length given, extends t top of wall, second bar to height ⅔ H, third bar to height ⅓ H.

When Type W is used as a bank wall (that is, above the roadway), ma: H = 20′; min. X = 2′ for H of 5 to 10′; and 0.2 H for H greater than 10

When Type W is used as a sustaining wall (that is, below the roadway max. H = 13′; and min. X = 3′, except where foundation is rock or entirel below frost.

When Type R is used as a bank wall, max. H = 20′; min. X = 0.15 for H greater than 10′.

When Type R is used as a sustaining wall, max. H = 13′; min. X = 0.2 H for H greater than 10′.

TABLE 117.—RETAINING WALLS, STATE OF PENNSYLVANIA

Cement Masonry						Dry Rubble Masonry						Concrete Masonry					
Ground Level with Top of Wall			Surcharged			Ground Level with Top of Wall			Surcharged			Ground Level with Top of Wall			Surcharged		
H.	T.	B.	H.	T.	B.	H.	T.	B.	H.	T.	B.	H.	T.	B.	H.	T.	B.
4′-0″	1′-6″	1′-8″	4′-0″	2′-0″	2′-3″	4′-0″	2′-0″	2′-0″	4′-0″	2′-0″	2′-7″	4′-0″	1′-6″	1′-6″	4′-0″	1′-6″	2′-0″
5′-0″	2′-0″	2′-0″	5′-0″	2′-0″	2′-10″	5′-0″	2′-0″	2′-6″	5′-0″	2′-0″	3′-4″	5′-0″	1′-6″	1′-9″	5′-0″	1′-6″	2′-5″
6′-0″	2′-0″	2′-5″	6′-0″	2′-0″	3′-5″	6′-0″	2′-0″	3′-0″	6′-0″	2′-0″	4′-0″	6′-0″	1′-6″	2′-2″	6′-0″	1′-6″	2′-10″
7′-0″	2′-0″	2′-10″	7′-0″	2′-0″	3′-10″	7′-0″	2′-0″	3′-6″	7′-0″	2′-0″	4′-7″	7′-0″	1′-6″	2′-5″	7′-0″	1′-6″	3′-5″
8′-0″	2′-0″	3′-3″	8′-0″	2′-0″	4′-6″	8′-0″	2′-0″	4′-0″	8′-0″	2′-0″	5′-4″	8′-0″	1′-6″	2′-10″	8′-0″	1′-6″	3′-10″
9′-0″	2′-0″	3′-7″	9′-0″	2′-0″	5′-0″	9′-0″	2′-0″	4′-6″	9′-0″	2′-0″	5′-10″	9′-0″	1′-6″	3′-2″	9′-0″	1′-6″	4′-4″
10′-0″	2′-0″	4′-0″	10′-0″	2′-0″	5′-7″	10′-0″	2′-0″	5′-0″	10′-0″	2′-0″	6′-7″	10′-0″	1′-6″	3′-6″	10′-0″	1′-6″	4′-10″

Cement.—Top of wall not less than 1′-6″, 2′-0″ if possible. Face battered; back perpendicular. Weep holes with blind drain in wet localities.

Dry Rubble.—Top of wall not less than 2′-0″. Face battered; back perpendicular. Courses perpendicular to face batter Face of wall pointed. Weep holes with blind drain in wet localities.

Concrete.—Top of wall not less than 1′-6″. Face battered 1: 12; back battered or stepped. Weep holes with blind drain in wet localities. Expansion joints every 25′-0″.

All offsets 6″. Bottom of footing below frost line. (Depth of footing at least 3′.) Backfilling done with acceptable material placed in layers of not less than 6″ and thoroughly rammed. (See page 684 for Typical Sections.)

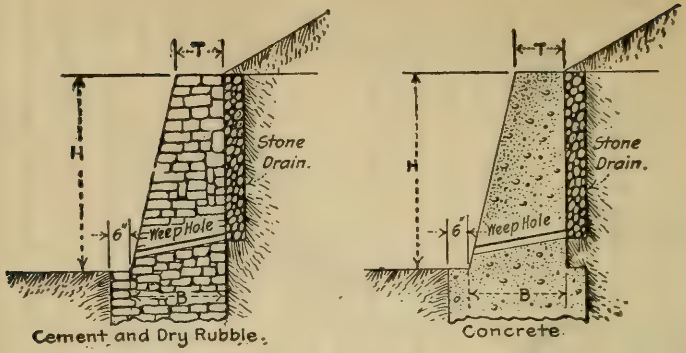
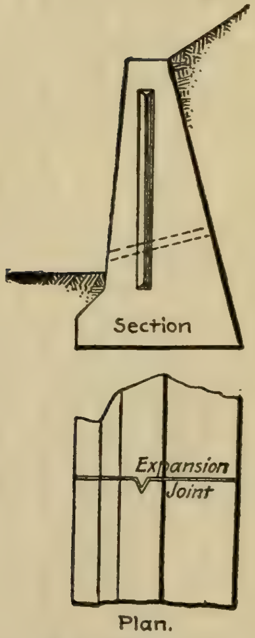


FIG. 235.—State of Pennsylvania retaining walls.
(To accompany Table 117 page 683.)



Key Expansion Joint.

FIG. 236*A*.

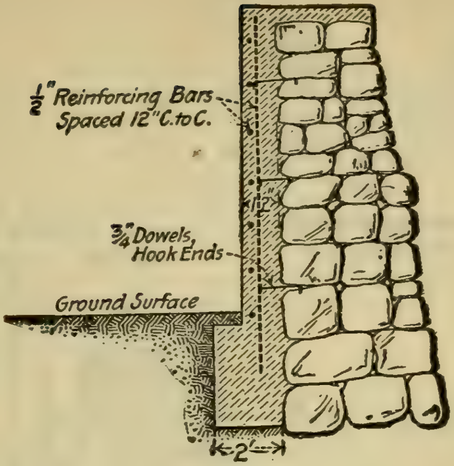


FIG. 237.—Facing old masonry.

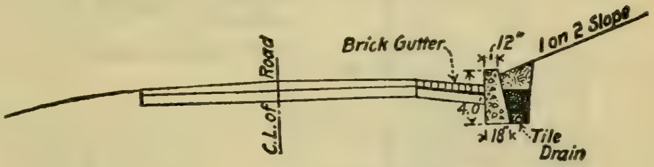


FIG. 238.—Typical toe wall.

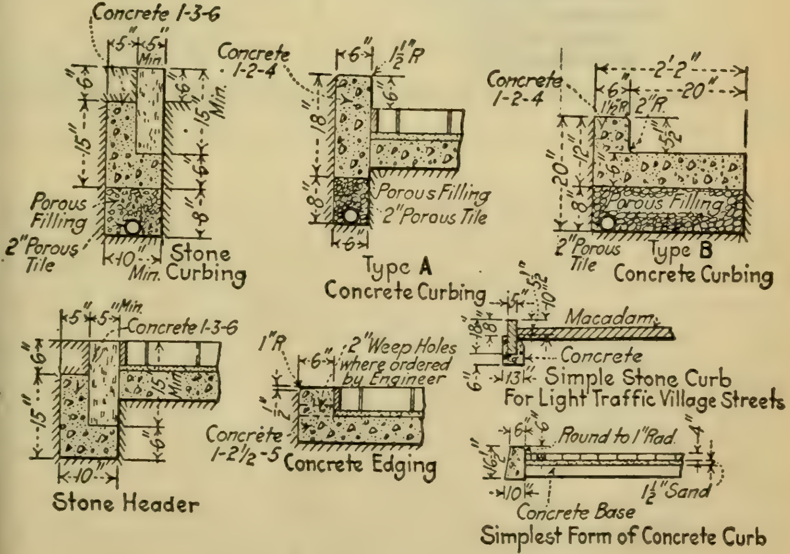


FIG. 239.—Typical curb details.

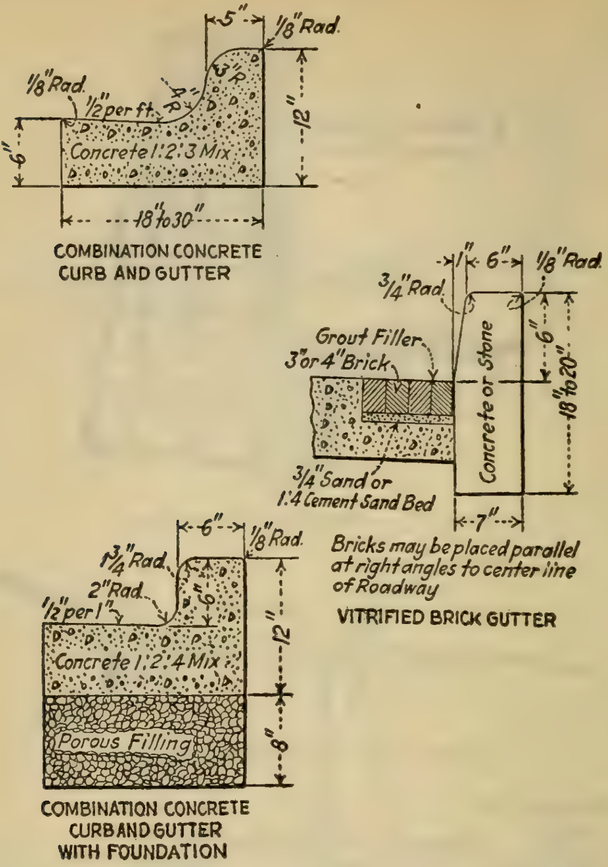


Fig. 239A.—Typical curb details U. S. Bureau Public Roads (1926)

Concrete gutters are in common use but are not so satisfactory as the cobble or brick gutter except on short hills where the gutter is directly adjacent to a concrete pavement.

Catch Basins.—Figure 242 shows ordinary rural highway catch basins and drop inlets. Figure 243 shows a satisfactory curb inlet city or village catch basin. Catch basins are to be avoided on rural highways if possible as the grate tends to clog and cause ponding. Where they are necessary, some clear opening not entirely covered by the grate should be provided.

Guide and Danger Signs.—Signs add to the convenience and safety of travel. Good examples of standard practice are shown in Figs. 252 and 197. The indiscriminate use of danger signs is inadvisable. Their use should be confined to actual danger condi-

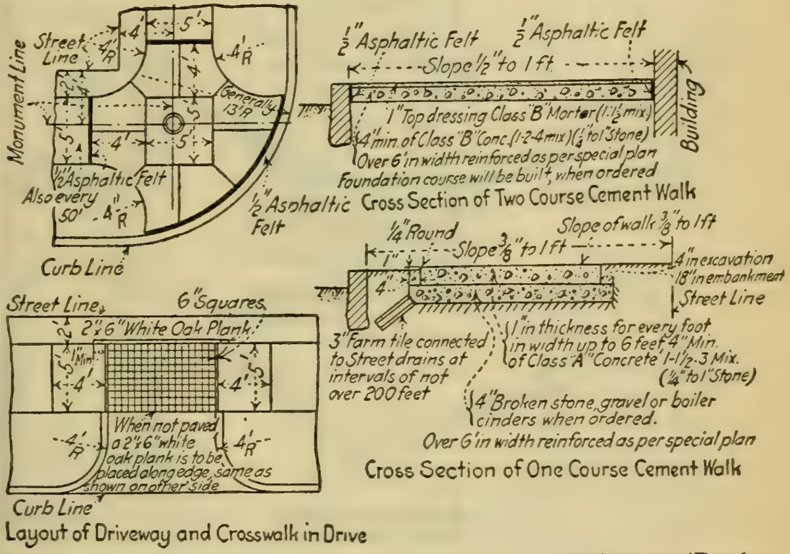


FIG. 240.—Typical sidewalk detail and curb corner layout (Rochester, N. Y.).

tions and they should be placed so that headlights at night will show them up easily. This last requirement generally results in placing them about 3 to 4′ from the edge of the pavement on the right side and not over 3′ above ground and preferably about 18″ above the shoulder to the bottom of the sign. The height and location must be worked out for each case and depend on alignment and grades.

The matter of location and height of signs is entitled to careful study for each individual case. There are, however, certain well-defined principles of location and height. The caution or danger sign should be located far enough from the point of danger to warn the driver in time for him to get his car under perfect control. This requires approximately 500′ on steep down grades, 250′ steep up grades, and about 300 to 350′ on ordinary light grades. The distance from the danger point should not be made any greater than

(text continued on page 689.)

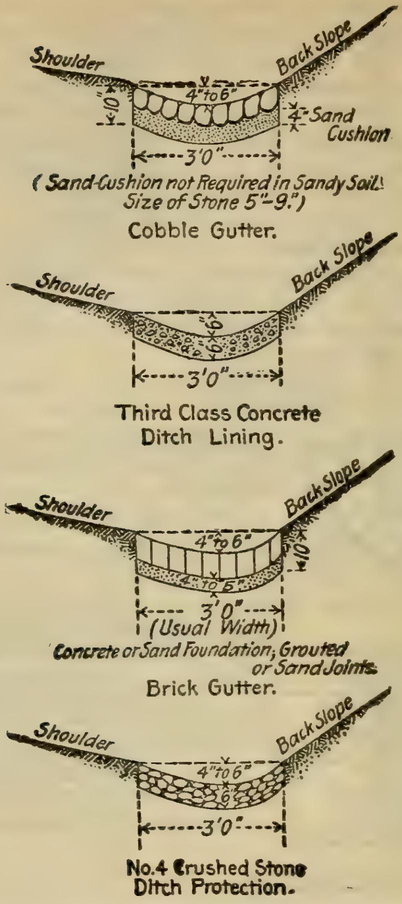


FIG. 241.—Typical ditch protections.

ıecessary, however. It is well established that the sign should be ›n the right side of the road and as near the pavement as possible vithout danger of being hit. Just back of the curb line on streets ınd from 3 to 4′ off the edge of pavement on rural highways are ;ood locations. At dead end roads or very sharp turns it is desir- ıble to place an additional large danger sign beyond the turn lirectly in line with the approach center line.

On the height of the sign depends the ease with which it is seen ›oth day and night. In the daytime a distinctive sign can be eadily seen at any elevation between 1 and 6′ above the road. The ıeight is controlled, therefore, by night driving conditions, which

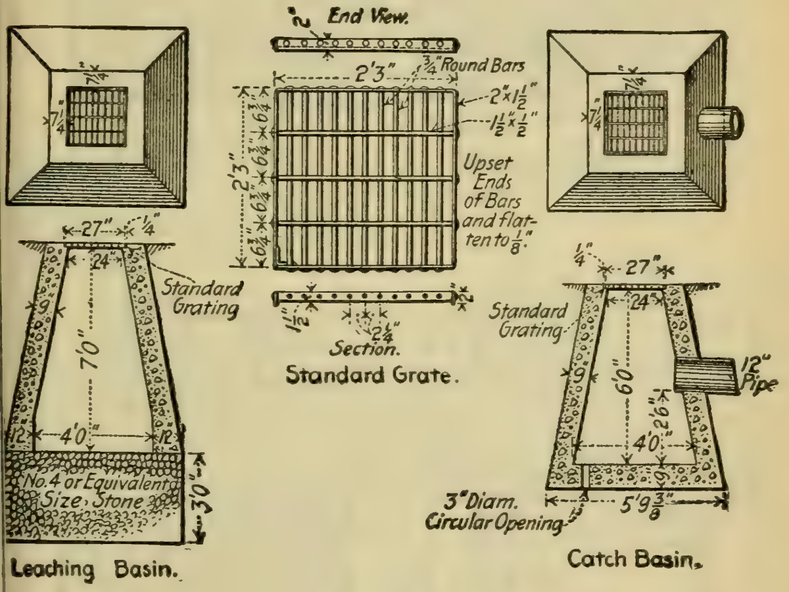


FIG. 242.

·quire a low position for proper headlight illumination. During ıe summer months when there is no snow on the ground, the best ·ight is approximately 18″ from ground elevation to the bottom of ıe sign. In winter the reflection on the snow permits a ·ight of 36″. Drifting snow makes the 36″ height desirable. ›r northern climates the danger signs should be of adjustable ·ight, the lower height being used in summer and the higher in inter.

Figure 197 shows good typical locations and heights.

Signs should be uniform in color, shape, and symbols. The llowing quotation gives the most recent recommendations for ıiform signals (1926).

(text continued on page 697.)

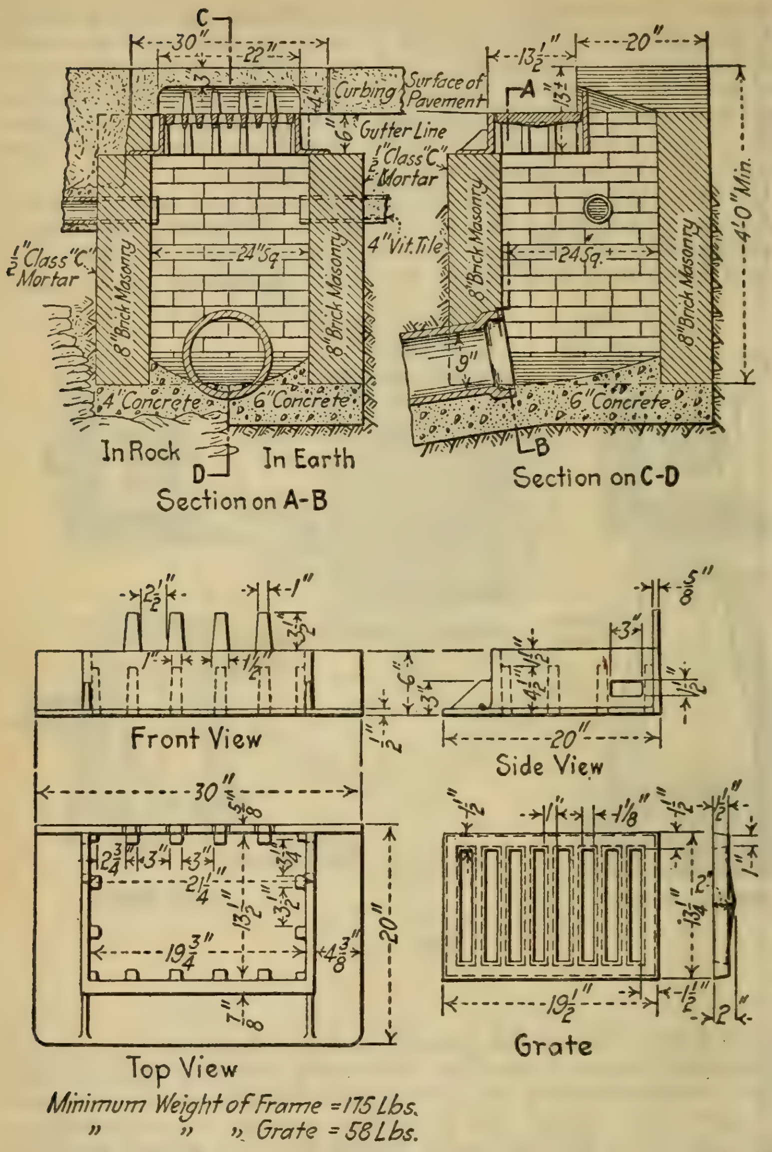
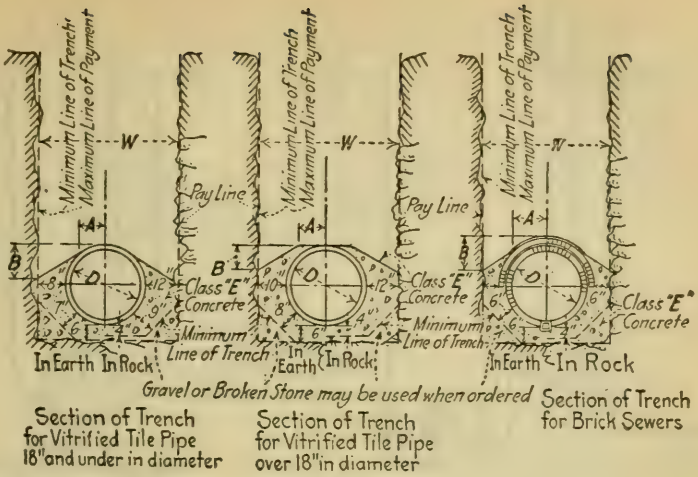


FIG. 243.—Typical curb inlet catch basin (City of Rocheste Standard).



Classification for Concrete					
Class	A	B	C	D	E
Prop.	1:1 1/2:3	1:2:4	1:2 1/2:5	1:3:6	1:8
Aggregate	1/4" to 1" Stone	1/4" to 1" Stone	1/4" to 1 1/2" Stone	1/4" to 2" Stone	Torpedo Gravel

Classification for Mortar				
Class	A	B	C	D
Prop.	1:1	1:1 1/2	1:2 1/2	1:3

Pipe Sewers 18" and Under							
In Earth				In Rock			
D	W	A	B	D	W	A	B
6"	23 1/4"	2 5/8"	6 1/4"	6"	31 1/4"	2 5/8"	8 5/8"
8"	25 1/2"	3 3/8"	6 3/4"	8"	33 1/2"	3 3/8"	9 1/8"
9"	26 3/4"	3 3/4"	7 1/8"	9"	34 3/4"	3 3/4"	9 3/8"
10"	27 3/4"	4 1/8"	7 3/8"	10"	35 3/4"	4 1/8"	9 5/8"
12"	30"	5"	7 7/8"	12"	38"	5"	10 1/8"
15"	33 1/2"	6 1/4"	8 3/4"	15"	41 1/2"	6 1/4"	11"
18"	37"	7 3/8"	9 3/8"	18"	45"	7 3/8"	11 7/8"

Pipe Sewers Over 18"							
In Earth				In Rock			
D	W	A	B	D	W	A	B
20"	43 1/2"	7 1/2"	8 1/4"	20"	47 1/2"	7 1/2"	9 3/8"
22"	45 7/8"	8 1/4"	8 1/2"	22"	49 5/8"	8 1/4"	9 5/8"
24"	48"	9"	8 5/8"	24"	52"	9"	9 7/8"
27"	51 5/8"	10 1/4"	9 1/8"	27"	55 1/2"	10 1/4"	10 1/4"
30"	55 7/8"	11 1/4"	9 3/8"	30"	59"	11 1/4"	10 5/8"

Brick Sewer 30" and Over in Rock and Earth			
D	W	A	B
30"	4'-11"	16 1/2"	14 3/8"
33"	5'-2"	17 5/8"	15"
36"	5'-5"	18 3/4"	15 5/8"
42"	5'-11"	20 7/8"	17"
45"	6'-2"	21 7/8"	17 3/4"
48"	6'-5"	23"	18 5/8"

FIG. 244.—Sewer trenches.

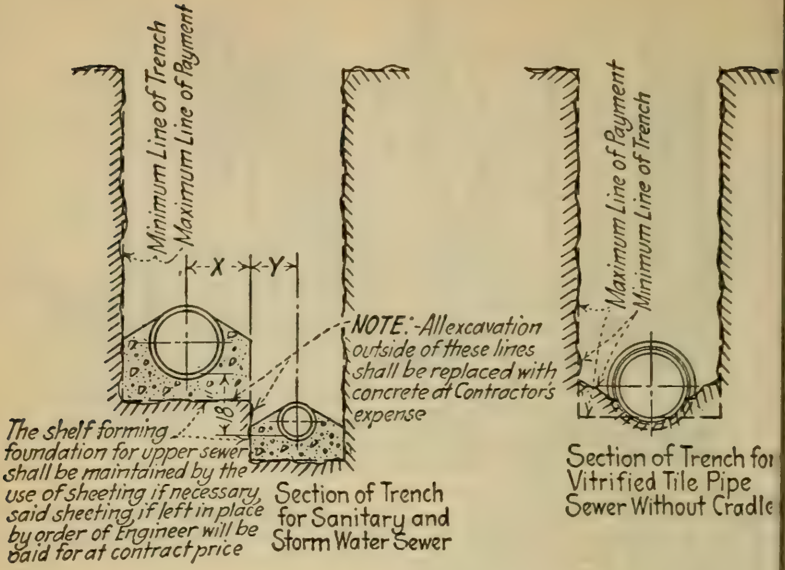


Table Showing Distances X and Y for Sewers laid in the same Trench, the Distance between center lines of Pipes = X+Y.
The total width of Trench paid for and the minimum excavation width = 2X+2Y

Kind	Size	In Earth		In Rock		Kind	Size	In Earth		In Rock	
Tile Pipe		X	Y	X	Y	Tile Pipe		X	Y	X	Y
" "	6"	11 5/8"	11 5/8"	15 3/4"	15 3/4"	" "	24"	24"	24"	26"	26"
" "	8"	12 3/4"	12 3/4"	16 7/8"	16 7/8"	" "	27"	25 3/4"	25 3/4"	27 3/4"	27 3/4"
" "	9"	13 3/8"	13 3/8"	17 3/8"	17 3/8"	" "	30"	28"	28"	29 1/2"	29 1/2"
" "	10"	13 7/8"	13 7/8"	17 5/8"	17 5/8"	Brick	30"	2'-5 1/2"	2'-5 1/2"	2'-5 1/2"	2'-5 1/2"
" "	12"	15"	15"	19"	19"	"	33"	2'-7"	2'-7"	2'-7"	2'-7"
" "	15"	16 3/4"	16 3/4"	20 3/4"	20 3/4"	"	36"	2'-8 3/8"	2'-8 3/8"	2'-8 3/8"	2'-8 3/8"
" "	18"	18 1/2"	18 1/2"	22 1/2"	22 1/2"	"	42"	2'-11 1/2"	2'-11 1/2"	2'-11 1/2"	2'-11 1/2"
" "	20"	21 3/4"	21 3/4"	23 3/4"	23 3/4"	"	45"	3'-1"	3'-1"	3'-1"	3'-1"
" "	22"	23"	23"	24 3/4"	24 3/4"	"	48"	3'-2 1/2"	3'-2 1/2"	3'-2 1/2"	3'-2 1/2"

FIG. 245.—Miscellaneous street standards (City of Rocheste
Sewer trenches.

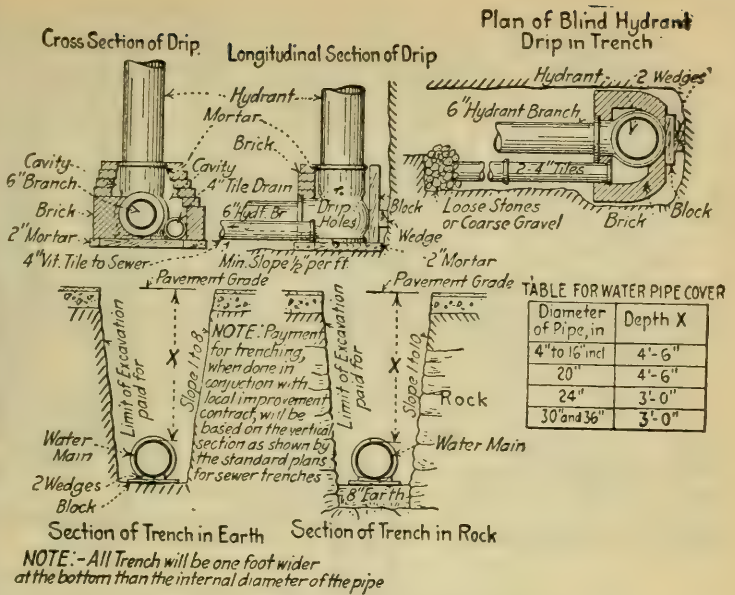
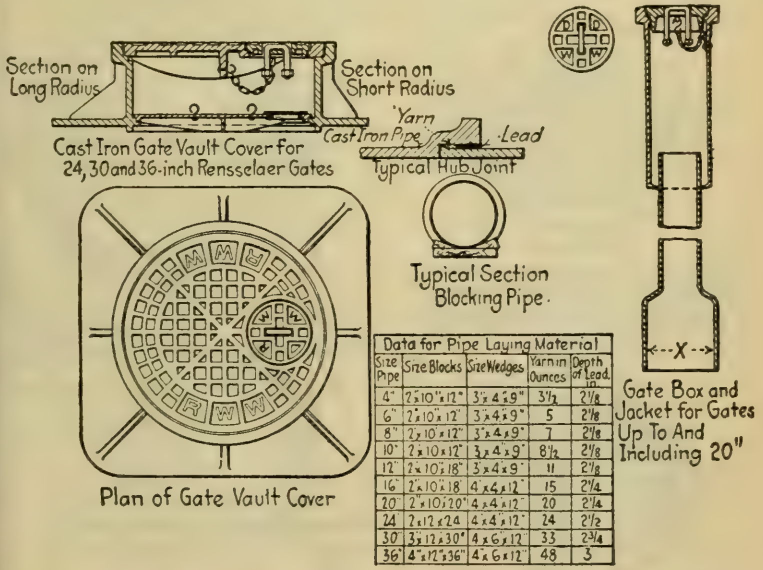


TABLE FOR WATER PIPE COVER

Diameter of Pipe, in	Depth X
4" to 16" incl	4'-6"
20"	4'-6"
24"	3'-0"
30" and 36"	3'-0"

FIG. 246.—Water pipe trenches.



Data for Pipe Laying Material

Size Pipe	Size Blocks	Size Wedges	Yarn in Ounces	Depth of Lead in.
4"	2"x10"x12"	3"x4"x9"	3½	2⅛
6"	2"x10"x12"	3"x4"x9"	5	2⅛
8"	2"x10"x12"	3"x4"x9"	7	2⅛
10"	2"x10"x12"	3"x4"x9"	8½	2⅛
12"	2"x10"x18"	3"x4"x9"	11	2⅛
16"	2"x10"x18"	4"x4"x12"	15	2¼
20"	2"x10"x20"	4"x4"x12"	20	2¼
24"	2"x12"x24"	4"x4"x12"	24	2½
30"	3"x12"x30"	4"x6"x12"	33	2¾
36"	4"x12"x36"	4"x6"x12"	48	3

FIG. 247.—Miscellaneous street standards (City of Rochester). Water trenches, etc.

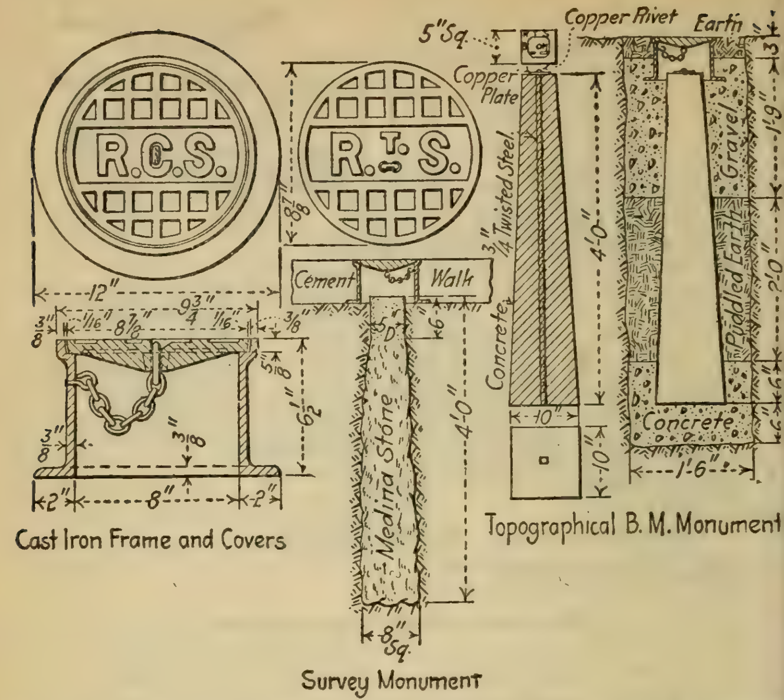


FIG. 248.—Miscellaneous street standards (City of Rochester

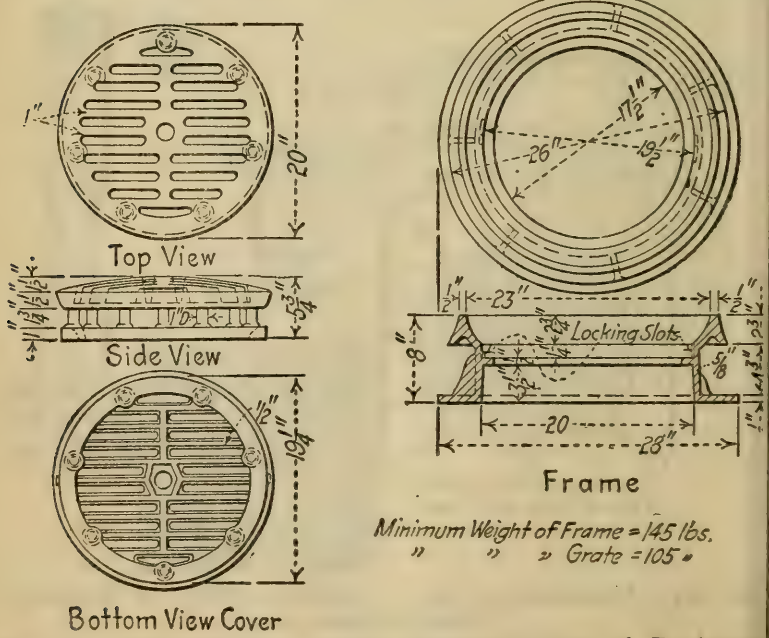
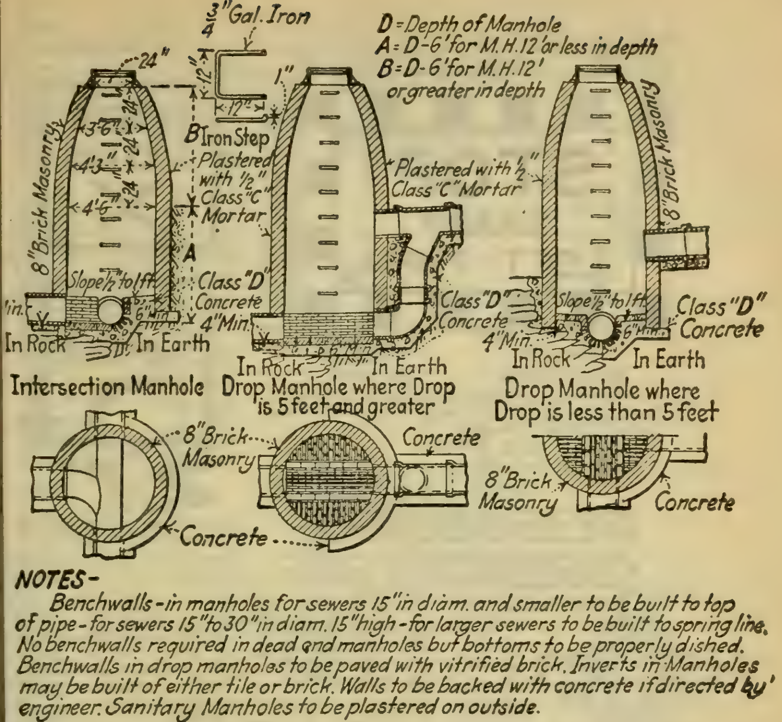
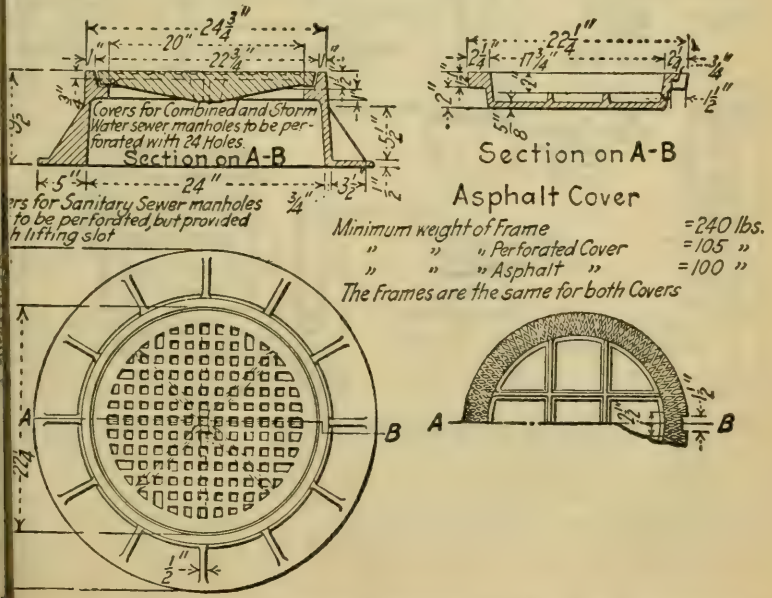


FIG. 249.—Miscellaneous street standards (City of Rochester



:. 250.—Miscellaneous street standards (City of Rochester). Manholes.



251.—Miscellaneous street standards (City of Rochester). Manhole covers.

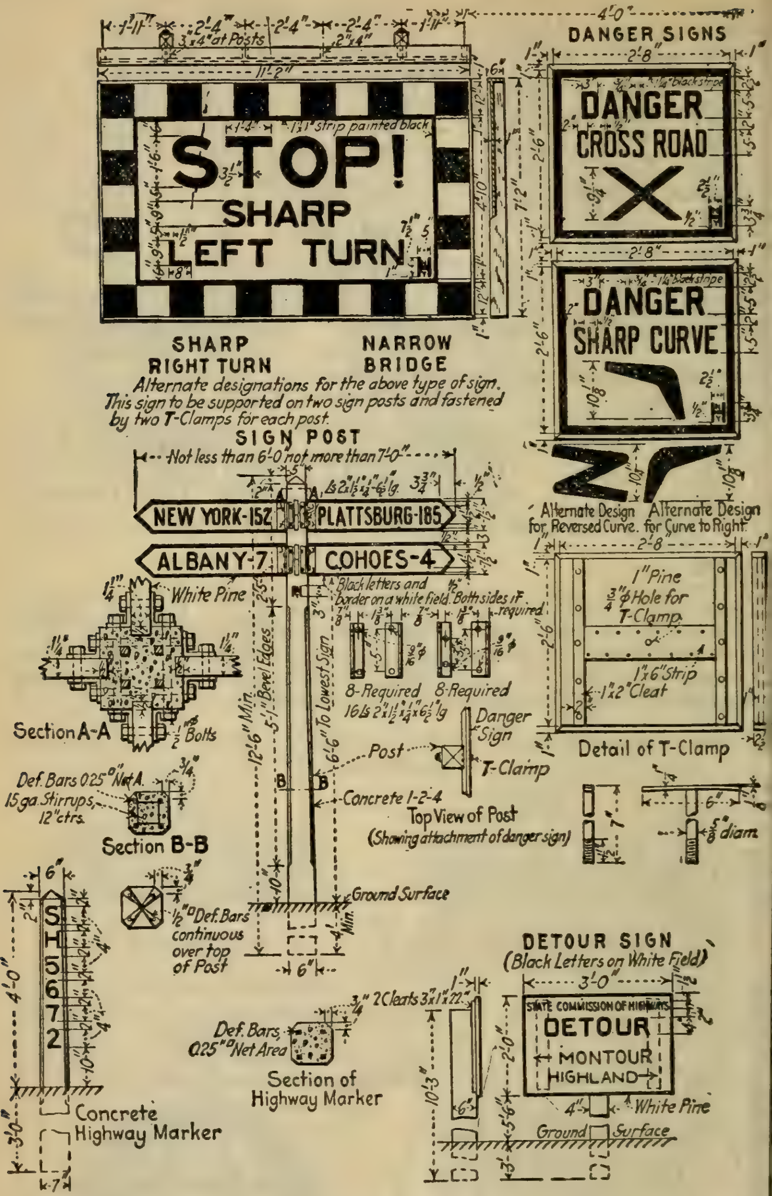


FIG. 252.—Typical guide and danger signs N. Y. State 1924.

HIGHWAY SIGNS AND SIGNALS

ecommendations of Subcommittee on Traffic Control and Safety Presented at San Francisco Meeting of American Association of State Highway Officials

Color of Signs.—Color of illuminated highway signs and signals.
RED to indicate STOP.
YELLOW to indicate CAUTION.
GREEN to indicate GO.

"These are the colors most generally used in railroad operations and are ow quite generally used in highway work. It is believed that they should e universally adopted in regulation of traffic on the highway.

COLOR OF NON-LUMINOUS SIGNS

Sign	Background	Copy[1]
top	Red center panel White upper and lower panels	White Black
aution	Yellow	Black
o or safety	Green	White
oad markers, guide, direction, general information	White	Black

[1] Owing to the lack of visibility of red in non-luminous signs at night, the pper and lower panels are made white which, because of the contrast, will ake a very conspicuous sign and at the same time retain the red which ould be universally used for Stop.

"The first three colors are the same for non-luminous signs as for the minous signs. It is believed that by keeping these colors the same, most nfusion can be avoided. Because of their simplicity and agreeing with the minous signs, it will be an easy matter to impress the color scheme clearly pon the minds of drivers, and even school children. No confusion should sult with this color scheme universally adopted.

"**Shapes of Non-luminous Signs.**—While the color on the non-luminous gns will be important, it is believed that a variation in shapes, varying ith the different degrees and kinds of danger and information will be most fective. It is a well-known fact that the shape of a sign is distinguishable ng before the copy or symbols thereon can be recognized; hence, the imporance of the variable shapes. In order to simplify and reduce cost of production it is necessary that these shapes be such that they can be produced t lowest cost.

"The following shapes are recommended:

Sign	Shape
ailroad prewarning sign	Round
top sign	Octagonal
low signs	Diamond shape
aution signs	Square
peed-limit sign	Rectangular (greatest dimension vertical)
oad markers	Shaped to fit the design of marker
uide and direction signs	Arrow or rectangular
eneral information	Rectangular

"**Sizes of Non-luminous Signs.**—While it is believed a standard size of e various signs should, in general, be used, it is also believed that in rare stances the most extreme danger points may well be marked by a larger gn than the standard in order to provide the increased warning.

"**Copy on Non-luminous Signs.**—The copy on non-luminous signs should e brief and simple and easily read. It is believed that clear English is, in neral, better understood than any combination of symbols and signs and, nce, English words are recommended rather than meaningless symbols.

"Hence, it is believed that the most effective set of standard signs can be ade by a proper combination of variable shapes and colors together with itable copy and dimensions."

Reflectors.—The use of reflectors to indicate danger is effective in some locations. They have a very limited usefulness on rural roads due to difficulty in placing them where they can catch the rays of approaching headlights in time. In fog, rain, and snow storms reflectors are of small value, for their efficiency is greatly reduced.

Traffic Lane Markings.—Probably the most effective and cheapest device to increase safety is the traffic lane marking. It has a very powerful effect on drivers, and keeps them on their own side

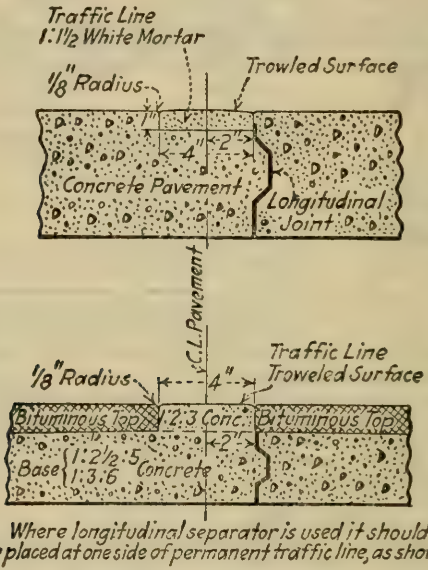


FIG. 252*A*.

of the road, particularly on curves and at the top of hills where th view is obscured.

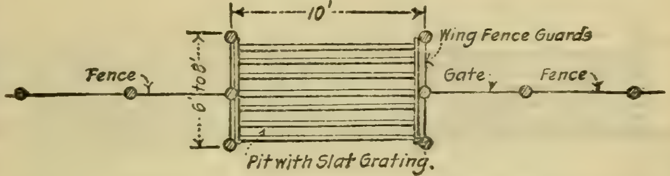
Figure 252*A* shows the method used on concrete base pavements For the usual concrete pavement the lane is marked by the longitudinal joint line. On macadam, sheet asphalt, brick, etc. it i marked with paint or adhesive strips. On these last-name pavements where paint is used the markings are generally confine to curves and to the top of hills.

Trolley Track and Crossing Details.—Figure 40 gives the essentials of elevation, clearance, and construction details where track are an integral part of the pavement design. The standard show is the New Jersey practice (see also p. 176).

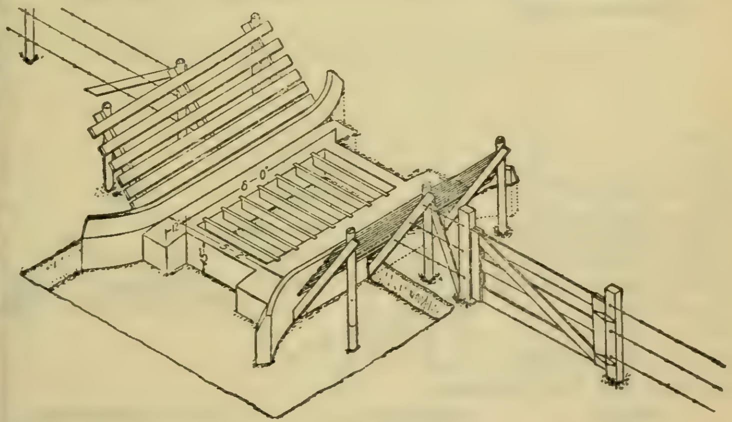
Monuments—Figure 249, Miscellaneous Standards, gives goo practice in the manner of permanent street monuments. Th sam type of marker 6″ above ground makes a good road right-o way marker.

Cattle Guards.—In western territory, ranch owners will often rant road right of ways for a nominal sum, but stipulate that the ight of way shall not be fenced, as it would cut off part of their ange from water. The boundaries of these ranges are generally enced, and where the road passes this fence a gate must be used to revent straying of cattle; it is more or less of a nuisance for every ser of the road to open and close the gate, and generally a gap is left 1 the fence across which a shallow pit 2 to 3′ deep is dug. This is overed with a slat grating over which cattle will not walk but ver which automobiles can be driven (Fig. 253).

Cattle Passes.—The minimum size of opening which will serve atisfactorily for tunnel passageways under highways is 6 by 6′.



Cattle guard in New Mexico.



IG. 253.—Type of crossing used extensively in Western Kansas.

Fences.—Ordinary right-of-way and snow fences are shown in gs. 254 and 255.

Rural Highway Illumination.—Illumination is the final stage of nprovement of rural highways. Effective lighting costs from 00 to $1,000 per mile per year. At the present stage of rural highay development (1926) it is only reasonable to incur this expense a limited mileage of road (see Table 2, p. 6).

Illumination is a good investment on main commercial intercity uling routes carrying a large amount of night traffic. It is also sirable and justifiable in suburban districts adjacent to cities, for promotes residential development and increases land values.

On the ordinary improved rural road, however, it is doubtful i such a large yearly expenditure is justified.

First-class illumination increases safety of night driving an increases safe night speeds 5 to 10 miles per hour. By good illumi nation is meant sufficient light to nullify the glare of approachin headlights and to indicate vehicles or pedestrians by either direc illumination or silhouette effect. Under good atmospheric condi tions and provided that the automobiles are operated with head lights dimmed, this can be accomplished with 200 to 250-cp. light located approximately 20′ above the road and spaced approximatel 250′ apart. This arrangement and intensity of lights, howeve will not nullify the glare of full-power headlights.

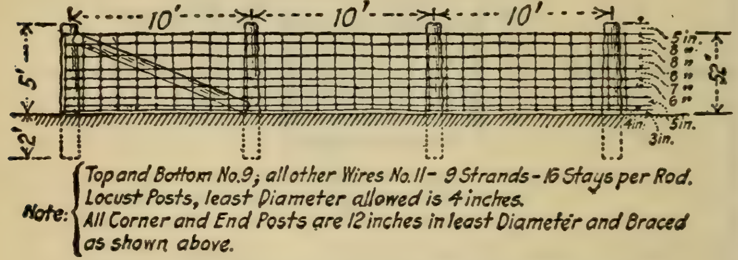


FIG. 254.—A good standard right-of-way fence.

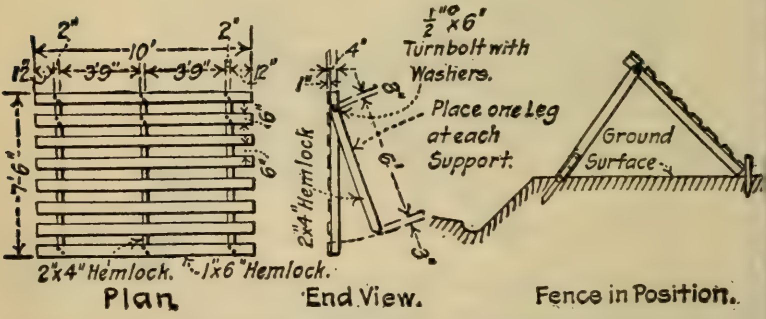


FIG. 255.—Snow fence detail.

In localities with which the author is familiar it has been four desirable to use 400-cp. lights spaced 250′ apart and located 2 above the road. The cost of 400-cp. lights is about $40 per lig per year and of 200-cp. lights about $35 per light per year (weste New York 1926 cost conditions). These 400-cp. lights seem effecti in nullifying objectionable glare of full-strength headlights und usual atmospheric conditions. In a bad rain storm or fog, howeve any artificial illumination is a nuisance, as reflection surroun each light with veritable curtain, which completely obscures objec beyond the light range.

THE LIGHTING OF STREETS AND HIGHWAYS

'rinciples and Practice Outlined in Paper Presented Nov. 13 at Annual Convention of American Society for Municipal Improvements

By Stephen Carleton Rogers

:ommercial Illuminating Engineer, Street Lighting Department, General Electric Co.

"Vision is accomplished in two ways, or in a combination of two ways. 'bjects, persons, etc., are seen either in silhouette against the lighted backround of the street surface or else by the direct light from the lamps them-elves. When objects are seen in silhouette, their bulk or outline is observed; 'hen objects are seen in perspective, or by direct light, their details or fea-ıres are distinguished. All objects, etc., therefore, whether by day or by ight, must be seen either in silhouette or in perspective, or by a combination : the two. These principles should be remembered, as street lighting, to a ery large degree, depends upon them, no matter what class of street light-ıg is being considered. Vision by silhouette has been known and recognized y artists for many years, but has been appreciated by the illuminating ıgineer for only a comparatively short time.

"Depending upon these two methods of vision are the two main types of ghting, which may be classified as follows:

1. Large-unit lighting.
2. Small-unit lighting.

"Large-unit Lighting.—If a large unit equipped with a diffusing globe, r example, either a 6.6-amp. luminous (magnetite) arc lamp or a 15,000-men incandescent (Mazda C) lamp, be placed on the side of a street some stance away, as, for instance, 300′, objects, persons, etc., will be seen more silhouette than in perspective. This is commonly termed "large-unit reet lighting," and the illumination will be of a maximum high intensity ıd from a concentrated light source. It is clear, therefore, that whenever rge-unit lighting is employed that silhouetting will be more generally used, ırticularly so when the lighting units are spaced quite a distance apart. he closer the units be spaced the more will perspective vision occur in ›njunction, of course, with silhouette vision. The diffusing globe will cut ›wn the candlepower of either of the large units just mentioned to about ›o. If, for instance, twelve 80-cp. incandescent lamps be grouped together ıd placed in a single large globe, the resultant illumination would be prac-:ally the same as with the use of the single large unit.

"Small-unit Lighting.—Suppose, however, that these twelve small, 80-cp. candescent lamps be distributed along the same street and uniformly aced. The result then would be known as "small-unit street lighting," e illumination will be fairly uniform but of low intensity and from dis-ibuted light sources. With this type of street lighting there will not be ough intensity for either silhouette or good perspective vision. These 'o distinct types of street lighting also produce entirely different psy-ological effects, as was shown during some street-lighting tests con-ıcted a few years ago, where it was shown that large-unit lighting is by far e superior and more essential for good street lighting from every angle.

"There is still a very important phase that should be considered, *viz.*, e status of large units versus small units, viewed from an economic point view. A city or town naturally, since it is the party that has to pay e bills, is most vitally interested in street lighting and its costs. Since ıny cities have a certain appropriation for street lighting, they usually ınt to know what type of lighting will give the best results for that given ıount of money, rather than what is the best street lighting it can get and en how much it will cost. According to prevailing conditions and rates it ll cost a city approximately $100 per year for each large unit and about 5 per year for each small unit, considering these sizes just referred to. ıis will mean something like three large units for every twelve small units, roughly, three times the total light flux with its accompanying increased ımination and better visual effect for the same total cost per year.

"Street Lighting Practice.—Street lighting, in general, may be divided o the following five classes:

"Class I. Main business streets—highly intensive or white-way illumi-tion.

"Class II. Secondary business streets—good general illumination.

"Class III. Boulevards and main residential thoroughfares.

"Class IV. Side residential streets—comparatively low illumination.

"Class V. Interurban or main automobile highways.

"**Main Business Street Lighting.**—The main business streets of a large city may be properly separated into two subdivisions, whereas in a smalle city this distinction is lacking—it being hard to tell where one type stops anc the other starts.

"*a.* Streets, whose stores are essentially retail and depend largely upor show windows for the display of their goods, merchandise, or wares—street that are of greatest distinction.

"*b.* Important business streets largely traveled at night.

"The type of lighting that should be employed should be such as to satisf every requirement of police protection, the motorist, the safety of th pedestrian, the merchant, the æsthetic sense, etc.

"In order to accomplish this result, the illumination of the street surfac must be of high intensity so that silhouette, together with perspective vision may be employed; cornices, facades, and other architectural details an effects must be brought out. In order to achieve these desired results, light ing units of high candle power closely spaced must be used, the units them selves must be attractive by day as well as by night, and they should b mounted upon ornamental standards, thereby doing away with unsightl overhead wires and trolley poles, etc. In large cities, two and three of thes large units per post, equipped with diffusing glassware, should be specifie with approximately 100′ spacing per side at 20–30′ heights. In cities of thi type the buildings range from six stories and upwards, so that a light dis tribution with nearly equal amount of light in upper and lower hemispher should be used. By the use of the new alabaster rippled glassware, the mos pleasing effects are produced. In the small cities, where the buildings ar rarely four to six stores high, excellent results may be obtained by the use c single lamp standards 15 to 18′ high, and when using the incandescent lam the dome refractor and light alabaster rippled globe may be used, as th particular combination has been designed so as to permit the illumination c building fronts of comparatively few stories' height and at the same tim considerably increase the illumination of the street surface. On the othe hand, suppose that a type of distribution should be used which has prac tically no light in the upper hemisphere, such as would be obtained from unit with clear globe and reflector or ordinary refractor installation (nc the dome refractor and rippled globes), what would be the result? Ther would be a sharp shadow, a sharp cut-off on the building fronts, which woul give a very unpleasant effect—absolutely wrong physiologically as we as psychologically.

"There is yet another factor that enters into lighting of this class—*viz* the quality of light. The chief difference between the magnetite arc lam and the incandescent lamp of equal intensity is the color. The color of th luminous (magnetite) arc lamp is the nearest approach to daylight of an artificial illuminant commercially exploited. This white color of the magne tite arc is considered by many to be unexcelled for certain classes of lighting– especially the high intensive class where there is show-window lighting. I order to get the most effective show-window lighting a soft, warm, lightin effect is most desirable, which is obtained when the ordinary incandescer lamp is used. When the streets are lighted, the effectiveness of the sho window is greatly decreased, if the color of the street lighting is the same a that of the show-window lighting, because contrast will be lacking. How ever, if the streets are lighted with the white color of the magnetite ai lamp, then the show windows will be in contrast with their warmer yello light, and the attractiveness of the windows will increase and they wi stand out in most beautiful fashion. This, in fact, is the accepted standar among those who are doing the highest-grade intensive lighting today.

"What would be the result if the windows should be lighted with whit light (thereby revealing correct color values) and the street lighted wit yellowish light? The contrast will be in the wrong direction, for the bacl ground will be cold and harsh and the foreground warm, whereas, the bacl ground must be warm and the foreground cold to satisfy. The revealin power, that is, the ability to pick up objects, etc., with white light is great than with yellow light.

"**Types of Refractors.**—It may be pertinent here to describe some of th various types of refractors in use, and show why only the dome refractor suitable for this class of lighting. The original refractor consisted of a seri of horizontal prisms, both above and below the light source, so as to redire all of the light flux both upward and downward at a predetermined ang in the hopes of approaching a uniform horizontal illumination. This pri ciple is, of course, fundamentally wrong, since non-uniform illumination of far more use in street lighting illumination. It was found that fairly goc

street illumination could be obtained by leaving off the prisms in the lower hemisphere, thereby not altering the downward direct light, but adding to the downward light at a given angle a large part of the upward light. In both of these refractors there is an external piece consisting of a series of vertical prisms so as to diffuse the light and lower the brilliancy, thus reducing the glare. If, now, either of these refractors is put into an ordinary diffusing globe, the refractive feature will be lost and the resultant illumination will be less than is obtained by leaving off the refractor.

"In the case of the dome refractor, however, there are no vertical prisms, two separate series of horizontal prisms in the upper hemisphere being used to redirect the upward light, thereby utilizing a larger spherical angle and a consequently greater amount of light flux. In order to reduce glare, a rippled glass globe is used which, when very lightly coated with alabaster, does not entirely nullify the directive feature of the refractor and at the same time spreads sufficient light upward for fairly high buildings. The asymmetric type of refractor, of course, takes even more light from the building fronts and should be used only for other classes of streets as described later.

"**Lighting of Secondary Business Streets.**—This classification should include those business streets not coming under Class I, in other words, those having comparatively little travel at night, those including largely wholesale stores, warehouses, factories, etc. In streets of this class the same type of illuminant should be used, the same intensity of unit, but longer spacing between lamps than in Class I. This is more advisable than going to the next smaller size unit and retaining the same spacing, although the cost per year may be the same, better visual effects may be obtained by fewer larger units than by more smaller units. The lighting of these streets is mostly done for police and fire protection.

"**Boulevards and Main Residential Thoroughfares Lighting.**—In this classification should also be included park lighting. These streets are used by automobilists and pedestrians, and the needs of each should be satisfied. Lamps best suited for this type of lighting should be of the ornamental types used for Classes I and II lighting, but spaced farther apart. Of course, the best results will be obtained by using the large 6.6-amp. luminous arc lamps or the 15,000-lumen incandescent lamps—however, very fine results can be obtained with the 4- or 5-amp. luminous arc lamps or the 6000- or 10,000-lumen incandescent lamps with rippled globes. It might be added that a semiornamental bracket type of unit giving the same light distribution can be used where overhead wiring is available, thereby saving the additional expense of ornamental standards and underground wiring.

"**Lighting Side Residential Streets.**—On account of the small amount of motor travel on this type of street, a less expensive unit can be well utilized here, one employing a 4000-lumen incandescent lamp serving the purpose admirably. A novel as well as utilitarian unit has recently been designed for this work. It consists of a single piece of glazed porcelain which acts as insulator and prismatic glass holder as well.

"**Interurban or Main Automobile Highway Lighting.**—These roads are the main traffic routes connecting towns and cities. The problem of lighting these is entirely changed, due to the ever-increasing auto traffic and headlight glare. Another factor enters into this class of lighting especially, namely, the character of the road surface. There are for all practical purposes three main types of road surfaces:

"1. Non-reflecting, non-diffusing—*viz.*, country roads with possibly a light coating of oil to lay the dust.

"2. Diffusing—light-dust, reinforced-concrete, cement roads.

"3. Reflecting—bituminous-macadam, asphalt, wood-block, etc., roads.

"The majority of these highways are of the latter two types, with the reflecting types in greater abundance. Because of these improved roads, it has been possible to design and utilize a special unit, consisting of a number of nested parabolic reflectors, making it possible for one lamp to be in the focus of six reflectors and thereby distributing the light along the road without any spilled or wasted light, as is the case with other than asymmetric distribution of light. In the case of the black-surface roads, it is possible, using 2500-lumen (250-cp.) lamps with spacing of 300′ and height of 30′, to make the road surface a veritable ribbon of light—to use the road surface as a secondary light source—to reduce glare from approaching automobile headlights by decreasing the contrast between them and their background. This type of lighting is one of the greatest advances in street illumination that has been made—it is very economical, especially when it is considered that it costs approximately $30,000 to $40,000 per mile for investment of the road itself as against $3000 per mile for the lighting units and lines, etc.

maintenance of the roads costs about $5000 per mile, as against $1000 per mile for the lighting. Some of the obvious advantages of this kind of lighting are as follows;

"I. Prevents accidents:

"1. By showing up dangerous curves.

"2. By reducing headlight glare.

"3. By illuminating signs, sides of roads, and obstacles.

"II. Adds to comfort of night driving:

"1. By relieving eyestrain.

"2. By assisting in making repairs.

"3. By discouraging holdups.

"III. Increases night traffic and thereby relieves day congestion.

"IV. Decreases running time and increases road capacity.

"V. Helps to bring electricity to the farm by providing a pole line.

"VI. Increases real estate values:

"1. By tending to extend the city along highways.

"2. By bringing electrical conveniences.

"As an illustration of what might be accomplished in the way of highway lighting from an economic point of view, take, for example, Massachusetts (and the same might apply to any other state). There are at present roughly, 1500 miles of improved state highway, which should be sceintifisally lighted. This would mean an initial investment of about $5,000,000 with a yearly maintenance cost of $1,500,000 (figuring an average cost of $60 per lamp year to the city or state). A few years ago drastic headlight laws were enacted, which, it has been conservatively estimated, cost the automobile owners more than $2,500,000 at that time, plus the additional amount necessary for their upkeep. If this money had been expended in the proper direction, headlights would be unnecessary and safety to all would have been increased.

Really complete lighting similar to city streets undoubtedly increases the amount of traffic a road can safely carry at night and for main commercial roads, where the freighting is carried on night and day, good illumination costing about $800 to $1000 per mile per year is undoubtedly more than justified on the score of being the cheapest and safest means of increasing road-carrying capacity at night.

CHAPTER XI

MATERIALS AND TESTS

Introductory Note.—This chapter duplicates a small amount of the data from different chapters but has not been rearranged, as such duplications add to the ease of reference.

Materials.—The selection of materials is an important part of the design. Most municipal and state departments have well-equipped laboratories for testing stone, gravels, brick, bitumens, cements, etc. The object of these tests is to determine the physical and chemical properties that have a particular bearing on the action of the materials under construction conditions. While these conditions are not attained, they are approximated, and by a comparison of the laboratory results with the actual performance of the different materials in practice a relation can be established that is useful as a basis for judgment.

The authors are greatly indebted to H. S. Mattimore and J. E. Myers, who have rearranged and brought up to date much of the material on tests and their significance.

This chapter gives a brief statement of the desirable qualities and tests for:

1. Top course, macadam stone.
2. Screenings.
3. Bottom course, macadam stone.
4. Bottom course and subbase fillers.
5. Brick.
6. Bituminous binders.
7. Cement (Portland).
8. Fine aggregate for cement or bituminous concretes.
9. Coarse aggregate for cement concrete.
10. Sand-clay and gravel tests.

Instructions for sampling materials are given in Chap. XII, page 752.

1. STONE FOR THE SURFACING OF MACADAM ROADS

Stone for use in the surfacing of a macadam road should be hard and tough to withstand the abrasive action of team traffic and the vibratory action of high-speed motor vehicles, and should not contain any minerals that are likely to disintegrate rapidly under the influence of weather conditions.

To determine the relative hardness, toughness, and power to resist abrasive and impact action of traffic, stones are subjected to the following tests:[1]

[1] American Society of Testing Materials.

1. Abrasion.
2. Hardness.
3. Toughness.
4. Specific gravity.
5. Absorption.
6. Fracture.
7. Geological classification.

"**Abrasion Test.**[1]—The machine shall consist of one or more hollow iron cylinders; closed at one end and furnished with a tightly fitting iron cover at the other; the cylinders to be 20 cm. in diameter and 34 cm. in depth inside. These cylinders are to be mounted on a shaft at an angle of 30° with the axis of rotation of the shaft.

"At least 30 lb. of coarsely broken stone shall be available for a test The rock to be tested shall be broken in pieces as nearly uniform in size as possible, and as nearly 50 pieces as possible shall constitute a test sample The total weight of rock in a test shall be within 10 g. of 5 kg.

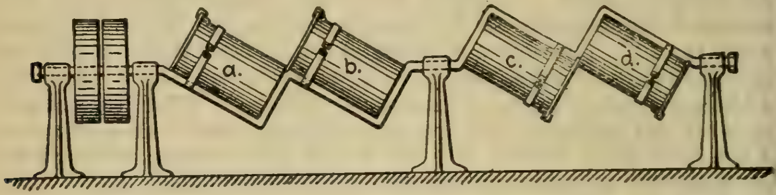


FIG. 256.—Deval rattler.

"All test pieces shall be washed and thoroughly dried before weighing Ten thousand revolutions, at the rate of between 30 and 33 per minute, sha constitute a test. Only the percentage of materials worn off which will pas through a 0.16-cm. (1/16") mesh sieve shall be considered in determining th amount of wear. This may be expressed either as the percentage of the 5 kg used in the test, or the French coefficient, which is in more general use, ma be given; that is,

Coefficient of wear $= 20 \times \frac{20}{w} = \frac{400}{w}$, where w is the weight in grams of th detritus under 0.16 cm. (1/16") in size per kilogram of rock used.

TABLE 118.—CONVERSION TABLE PER CENT OF WEAR TO FRENCH COEFFICIENT

French coefficient	% of wear	French coefficient	% of wear
20.0	2	8.0	5
13.3	3	6.7	6
10.0	4	5.7	7

"**Hardness.**[1]—Hardness is determined by a Dorry machine. A ston cylinder 25 cm. in diameter, obtained by a diamond core drill from th material to be tested, is weighed and placed in the machine so that one en rests on a horizontal cast-iron grinding disc with a pressure of 25 g. pe square centimeter. The disk is revolved 1000 times, during which standar crushed quartz sand about 1½ mm. in diameter is automatically fed to it The cylinder is then removed and weighed and the coefficient of hardnes obtained by the formula 20 − ⅓ the loss in weight, expressed in grams In order to get reliable results, two cylinders are generally used, each on being reversed end for end during the test.

[1] American Society of Testing Materials.

"**Test for Toughness.**[1]—1. Test pieces may be either cylinders or cubes, 25 mm. in diameter and 25 mm. in height, cut perpendicular to the cleavage of the rock. Cylinders are recommended as they are cheaper and more easily made.

"2. The testing machine shall consist of an anvil, 50 kg. in weight, placed on a concrete foundation. The hammer shall be of 2-kg. weight, and dropped upon an intervening plunger of 1-kg. weight, which rests on the test piece. The lower or bear surface of this plunger shall be of spherical shape having a radius of 1 cm. This plunger shall be made of hardened steel, and pressed firmly upon the test piece by suitable springs. The test piece shall be adjusted so that the center of its upper surface is tangent to the spherical end of the plunger.

"3. The test shall consist of a 1-cm. fall of the hammer for the first blow, and an increased fall of 1 cm. for each succeeding blow until failure of the test piece occurs. The number of blows necessary to destroy the test piece is used to represent the toughness, or the centimeter-grams of energy applied may be used.

"**Determination of the Apparent Specific Gravity of Rock.**[1]—The apparent specific gravity of rock shall be determined by the following method: First, a sample weighing between 29 and 31 g. and approximately cubical in shape shall be dried in a closed oven for 1 hr. at a temperature of 100°C. (230°F.) and then cooled in a desiccator for 1 hr.; second, the sample shall be rapidly weighed in air; third, trial weighings in air and in water of another sample of approximately the same size shall be made in order to determine the approximate loss in weight on immersion; fourth, after the balances shall have been set at the calculated weight, the first sample shall be weighed as quickly as practicable in distilled water having a temperature of 25°C. (77°F.); fifth, the apparent specific gravity of the sample shall be calculated by the following formula:

$$\text{Apparent specific gravity} = \frac{W}{W - W_1},$$

in which W = weight in grams of the sample in air and W_1 = the weight in grams of the sample in water just after immersion.

The apparent specific gravity shall be the average of three determinations made on three different samples.

"**Determination of the Absorption of Water per Cubic Foot of Rock.**[1]—The absorption of water per cubic foot of rock shall be determined by the following method: First, a sample weighing between 29 and 31 g. and approximately cubical in shape shall be dried in a closed oven for 1 hr. at a temperature of 110°C. (230°F.) and then cooled in a desiccator for 1 hr.; second, the sample shall be rapidly weighed in air; third, trial weighings in air and in water of another sample of approximately the same size shall be made in order to determine the approximate loss in weight on immersion; fourth, after the balances shall have been set at the calculated weight, the first sample shall be weighed as quickly as possible in distilled water having a temperature of 25°C. (77°F.); fifth, allow the sample to remain 48 hrs. in distilled water maintained as nearly as practicable at 25°C. (77°F.), at the termination of which time bring the water to exactly this temperature and weigh the sample while immersed in it; sixth, the number of pounds of water absorbed per cubic foot of the sample shall be calculated by the following formula:

$$\text{Pounds of water absorped per cubic foot} = \frac{W_2 - W_1}{W - W_1} \times 62.24, \text{ in which}$$

W = the weight in grams of sample in air, W_1 = the weight in grams of sample in water just after immersion, W_2 equals weight in grams in water after 48 hours immersion and 62.24 = the weight in pounds of a cubic foot of distilled water having a temperature of 25°C. (77°F.).

"Finally, the absorption of water per cubic foot of the rock, in pounds, shall be the average of three determinations made on three different samples according to the method above described.

"**Fracture.**—Stone suitable for road work should crush in cubical shapes rather than in thin, flat pieces, and preferably with rough jagged fracture that it may interlock firmly under action of the roller.

"**Geological Classification.**—The geological classification is determined from an examination with a microscope or powerful hand glass, and a consideration of its origin. Great refinements are avoided as the general classification is all that is necessary to the highway engineer after the physical qualities are ascertained by test."

[1] American Society of Testing Materials.

TABLE 119.—GEOLOGICAL CLASSIFICATION

Class	Type	Family
I. Igneous	1. Intrusive (plutonic)	a. Granite b. Syenite c. Diorite d. Gabbro e. Peridotite
	2. Extrusive (volcanic)	a. Rhyolite b. Trachyte c. Andesite d. Basalt and diabase
II. Sedimentary	1. Calcareous	a. Limestone b. Dolomite
	2. Siliceous	a. Shale b. Sandstone c. Chert (flint)
III. Metamorphic	1. Foliated	a. Gneiss b. Schist c. Amphibolite
	2. Non-foliated	a. Slate b. Quartzite c. Eclogite d. Marble

TABLE 120.—TAKEN FROM BULLETIN 31, U. S. OFFICE OF PUBLIC ROADS

Rock varieties	Per cent wear[a]	Toughness	Hardness	Cementing value	Specific gravity
Granite	3.5	15	18.1	20	2.65
Biotite-granite	4.4	10	16.8	17	2.64
Hornblende-granite	2.6	21	18.3	30	2.76
Augite-syenite	2.6	10	18.4	24	2.80
Diorite	2.9	21	18.1	41	2.90
Augite-diorite	2.8	19	17.7	55	2.98
Gabbro	2.8	16	17.9	29	3.00
Peridotite	4.0	12	15.2	28	3.40
Rhyolite	3.7	20	17.8	48	2.60
Andesite	4.7	11	13.7	189	2.50
Fresh basalt	3.3	23	17.1	111	2.90
Altered basalt	5.3	17	15.6	239	2.75
Fresh diabase	2.0	30	18.2	49	3.00
Altered diabase	2.5	24	17.5	156	2.95
Limestone	5.6	10	12.7	60	2.70
Dolomite	5.7	10	14.8	42	2.70
Sandstone	6.9	26	17.4	90	2.55
Feldspathic sandstone	3.3	17	15.3	119	2.70
Calcareous sandstone	7.4	15	8.3	60	2.66
Chert	10.8	15	19.4	27	2.50
Granite-gneiss	3.8	12	17.7	26	2.68
Hornblende-gneiss	3.7	10	17.1	30	3.02
Biotite-gneiss	3.2	19	17.5	41	2.76
Mica-schist	4.4	10	17.8	30	2.80
Biotite-schist	4.0	—	—	16	2.70
Chlorite-schist	4.2	—	—	24	2.90
Hornblende-schist	3.7	21	16.5	53	3.00
Amphibolite	2.9	10	19.0	29	3.00
Slate	4.7	12	11.5	102	2.80
Quartzite	2.9	19	18.4	17	2.70
Feldspathic quartzite	3.2	17	18.3	21	2.70
Pyroxene quartzite	2.3	27	18.6	17	3.00
Eclogite	2.4	31	17.4	21	3.30
Epodosite	3.6	16	16.0	47	3.03

[a] To convert % of wear to French coefficient, see table on page 706.

TABLE 121.—FROM ANNUAL REPORT N. Y. STATE HIGHWAY COMMISSION, 1914

County	Number of complete tests	Number of partial tests (no core piece)	Weight lbs. per cu. ft.	Water absorbed, lbs. per cu. ft.	French coefficient of abrasion	Hardness	Toughness	Weighted value
CALCAREOUS SANDSTONE								
Erie........	5	...	167	0.65	9.5	12.9	13.4	68
Saratoga....	6	...	169	0.31	10.1	15.9	13.8	76
Steuben....	4	1	162	1.44	9.4	15.1	13.1	72
DOLOMITE								
Clinton.....	6	...	175	0.41	11.9	15.8	12.7	80
Dutchess....	4	1	174	0.43	12.4	17.3	11.9	84
Essex.......	4	...	173	0.42	13.5	16.9	15.8	90
Franklin ...	4	...	174	0.51	9.5	14.9	12.1	70
Fulton......	4	...	176	0.15	11.8	16.1	14.4	82
Herkimer...	17	...	173	0.67	8.4	13.1	6.7	58
Monroe.....	13	2	171	1.07	10.3	14.8	8.2	69
Montgomery	8	...	174	0.39	10.6	14.7	11.3	73
Niagara.....	11	...	168	1.50	6.5	14.0	7.0	55
Saratoga....	8	...	174	0.33	8.6	15.5	9.2	66
St. Lawrence	31	...	174	0.65	10.5	15.7	9.9	73
Washington.	6	...	175	0.29	10.7	15.1	10.5	73
DOLOMITIC LIMESTONE								
Dutchess...	8	1	176	0.46	9.0	14.9	10.9	68
Herkimer...	4	1	170	0.47	11.3	16.7	8.2	76
Montgomery	8	1	175	0.41	13.0	15.8	12.4	83
Niagara....	7	...	166	2.19	9.5	13.1	7.8	63
St. Lawrence	7	...	168	0.38	9.2	16.8	6.8	68
Washington.	4	...	175	0.36	13.7	16.1	10.8	84
Wayne.....	4	...	173	0.59	10.2	15.5	8.7	71
GABBRO								
Essex.......	46	1	176	0.29	7.6	17.3	6.9	64
Warren.....	4	...	183	0.37	10.1	17.7	9.8	75
GNEISS								
Clinton.....	5	...	185	0.27	10.5	17.2	11.3	78
Dutchess....	8	1	172	0.58	7.0	17.1	9.1	64
Essex.......	29	2	176	0.31	8.4	17.1	8.1	68
Franklin....	8	...	178	0.50	6.2	16.1	7.8	59
Fulton......	12	1	169	0.25	11.1	17.8	11.5	80
Hamilton...	11	...	173	0.37	8.2	17.0	5.8	64
Jefferson....	26	1	171	0.23	11.1	17.3	12.0	80
Lewis.......	6	...	167	0.27	9.6	17.9	10.6	75
Orange.....	7	...	179	0.38	7.1	17.1	6.4	62
Putnam.....	10	1	172	0.32	8.5	16.6	7.5	66
Saratoga....	7	...	180	0.20	10.0	17.0	8.5	72
St. Lawrence	52	...	172	0.27	9.7	17.5	10.2	74
Warren.....	30	2	173	0.30	7.5	17.3	6.5	64
Washington.	4	...	170	0.29	8.5	17.1	10.9	71
Westchester.	37	2	171	0.39	8.3	16.9	7.8	67
GRANITE								
Essex.......	5	...	171	0.38	7.5	18.0	5.1	64
Franklin....	6	...	165	0.31	8.7	17.9	9.4	71
Hamilton...	5	...	165	0.36	9.9	18.1	9.0	75
Jefferson....	23	1	166	0.23	12.1	18.4	10.1	83
Lewis.......	8	...	166	0.36	10.9	18.4	9.2	79
Oneida.....	6	...	166	0.13	10.2	18.9	8.2	77
St. Lawrence	30	...	165	0.25	9.9	18.3	8.1	74
Warren.....	5	...	165	0.45	7.9	17.9	7.7	67

TABLE 121—*Continued*

County	Number of complete tests	Number of partial tests (no core piece)	Weight, lbs. per cu. ft.	Water absorbed, lbs. per cu. ft.	French coefficient of abrasion	Hardness	Toughness	Weighted value
LIMESTONE								
Albany.....	13	7	168	0.60	7.9	14.3	6.4	59
Cayuga.....	34	6	170	0.49	8.8	14.9	7.8	64
Clinton.....	14	2	170	0.28	8.2	14.1	5.3	58
Columbia...	12	...	170	0.28	9.1	15.3	9.2	67
Erie.........	9	3	167	0.57	8.1	16.6	8.3	66
Fulton......	6	1	168	0.21	7.7	15.5	6.5	60
Genesee....	6	3	169	0.26	8.0	15.0	8.2	62
Greene.....	11	...	169	0.36	11.1	16.4	8.9	75
Herkimer...	17	9	169	0.26	8.7	14.8	8.2	64
Jefferson....	105	44	169	0.28	7.6	15.1	6.4	59
Lewis.......	26	20	169	0.32	6.9	14.1	6.2	55
Madison....	16	1	169	0.23	8.4	14.7	7.7	62
Monroe.....	4	...	168	0.27	8.1	14.1	7.4	60
Montgomery	12	2	169	0.24	8.5	15.3	8.0	64
Niagara.....	11	1	168	0.84	7.1	12.8	6.5	53
Oneida.....	31	10	169	0.29	7.8	13.8	6.6	58
Onondaga...	25	1	170	0.38	8.9	15.7	8.4	67
Ontario.....	11	...	169	0.39	10.2	15.9	10.2	73
Otsego......	7	2	169	0.32	8.1	14.1	6.3	59
Rensselaer..	4	1	171	0.21	7.5	15.0	5.3	58
Saratoga....	5	...	170	0.24	8.7	13.7	7.0	60
Schoharie...	29	2	169	0.34	8.1	14.9	6.7	61
Seneca......	7	3	169	0.21	9.4	15.3	7.9	67
Ulster......	12	3	170	0.25	8.1	15.6	7.4	63
Warren.....	5	...	170	0.24	8.9	15.7	7.4	66
Washington .	5	3	169	0.34	7.9	15.5	6.9	62
MARBLE								
Dutchess....	4	...	178	0.30	7.3	14.2	6.0	55
QUARTZITE								
Columbia...	16	...	168	0.28	16.5	18.3	17.1	103
Dutchess....	8	2	166	0.36	13.5	18.8	11.8	90
Rensselaer..	10	...	166	0.49	12.1	18.7	14.8	89
Washington.	12	...	167	0.40	14.6	18.9	16.3	98
SANDSTONE								
Allegheny ..	8	...	156	2.10	8.4	13.4	9.1	61
Broome.....	11	...	165	1.29	7.8	12.9	10.5	60
Cayuga.....	4	1	167	1.16	7.8	12.1	10.5	58
Chenango...	15	1	164	1.58	8.7	11.2	10.4	59
Clinton.....	14	...	163	0.71	11.7	18.5	11.0	83
Delaware...	53	2	167	1.45	7.0	12.7	8.5	55
Erie.........	8	1	159	2.10	6.3	5.1	7.8	37
Franklin....	5	...	157	1.06	9.7	17.9	7.1	72
Greene.....	6	...	169	0.62	8.6	14.5	8.1	63
Herkimer...	4	...	160	2.50	10.9	16.4	10.7	76
Jefferson....	8	...	156	1.46	8.3	16.2	6.3	64
Livingston..	4	...	160	3.02	8.8	9.6	8.8	54
Madison....	5	...	163	2.15	9.9	13.9	8.6	66
Niagara.....	7	...	158	1.78	9.0	16.4	8.2	68
Orleans.....	8	...	155	2.18	11.8	14.4	8.1	72
Otsego......	21	1	162	1.75	8.4	11.9	9.6	59
Saratoga....	5	...	163	0.36	10.7	18.0	8.7	77

TABLE 121—*Continued*

County	Number of complete tests	Number of partial tests (no core piece)	Weight, lbs. per cu. ft.	Water absorbed, lbs. per cu. ft.	French coefficient of abrasion	Hardness	Toughness	Weighted value
			SANDSTONE.—*Continued*					
Schoharie...	6	3	165	1.21	9.4	15.2	11.7	70
Schuyler....	4	...	162	2.14	8.1	11.6	10.6	58
Seneca......	5	...	165	0.86	11.0	13.9	15.8	77
Steuben.....	22	3	157	2.79	8.3	9.3	10.0	54
St. Lawrence	16	...	159	0.79	10.0	17.8	7.2	73
Sullivan....	30	4	164	1.26	6.5	14.9	8.2	58
Ulster......	8	...	166	0.64	8.0	14.3	8.1	61
Wyoming...	7	...	159	2.54	6.0	5.1	7.9	36
			SANDY GRIT					
Albany.....	5	...	167	0.75	7.5	13.2	7.2	56
Columbia...	12	...	168	0.32	10.7	15.9	11.7	76
Dutchess....	10	2	168	0.57	8.1	16.2	11.5	68
Greene.....	13	...	169	0.48	7.1	15.6	9.5	62
Montgomery	4	...	166	1.39	10.1	11.3	11.8	65
Rensselaer..	10	...	169	0.44	9.1	15.9	9.4	69
Saratoga....	5	...	168	0.99	11.8	15.2	11.9	78
Schenectady	4	...	165	1.10	9.2	14.6	9.5	66
Ulster......	7	...	169	0.59	7.5	13.8	10.2	60
			SYENITE					
Essex.......	7	...	184	0.52	7.7	17.1	6.7	64
Franklin....	4	...	171	0.45	10.1	18.3	8.0	75
Herkimer...	13	...	174	0.16	12.5	18.0	11.6	85
Jefferson....	7	...	176	0.34	12.4	18.1	14.5	88
			TRAP					
Rockland...	12	...	183	0.39	13.2	17.6	1.64	91

The following quotation from *Bulletin* 31 Office of Public Roads describes the characteristics of the three groups:

"**Igneous Rocks.**—All rocks of the igneous class are presumed to have solidified from a molten state, either upon reaching the earth's surface or at varying depths beneath it. The physical conditions, such as heat and pressure, under which the molten rock magma consolidated, as well as its chemical composition and the presence of included vapors, are the chief features influencing the structure. Thus, we find the deep-seated, plutonic rocks coarsely crystalline with mineral constituents well defined, as in case of granite rocks, indicating a single, prolonged period of development, whereas the members of the extrusive or volcanic types, solidifying more rapidly at the surface, are either fine grained or frequently glassy and vesicular, or show a porphyritic structure. This structure is produced by the development of large crystals, generally by a recurrence of mineral growth during the effusive period of magmatic consolidation.

"In the arrangement of the rock families from a mineralogical standpoint, it will be noted that the plutonic-rock types, granite, syenite, and diorite, are represented by their equivalent extrusive varieties, rhyolite and andesite, and that diabase has been included, somewhat arbitrarily, with basalt, as a volcanic representative of gabbro. These latter rocks are of special interest, owing to their wide distribution and general use in road construction. They occur in the forms of dykes, intruded sheets, or volcanic flows, and vary in structure from glassy prophyritic (typical basalt) to wholly crystalline and even granular (diabase). Their desirable qualities for road building are caused to a large extent by a peculiar interlocking of the mineral components (ophitic structure), yielding a very tough and resistant material well qualified to sustain the wear of traffic.

"Igneous rocks vary in color from the light gray, pink, and brown to the acid granites, syenites, and their volcanic equivalents (rhyolite, andesite,

etc.) to the dark steel gray or black of the basic gabbro, peridotite, diabase, and basalt. The darker varieties are commonly called "trap." This term is in very general use and is derived from *trappa*, Swedish for stair, because rocks of this kind on cooling frequently break in large tabular masses, as may be seen in the exposures of diabase on the west shore of the Hudson River from Jersey City to Haverstraw.

"**Sedimentary Rocks.**—The sedimentary rocks as a class represent the consolidated products of former rock disintegration, as in the case of sandstone, conglomerate, shale, etc., or they have been formed from an accumulation of organic remains chiefly of a calcareous nature, as is true of limestone and dolomite. These fragmental or clastic materials have been transported by water and deposited mechanically in layers on the sea or lake bottoms, producing a very characteristic bedded or stratified structure in many of the resulting rocks.

"In the case of certain oolitic and travertine limestones, hydrated iron oxides, siliceous deposits, such as geyserite, opal, flint, chert, etc., the materials have been formed chiefly by chemical precipitation and show generally a concentric or colloidal structure.[1] Oölitic and pisolitic limestones consist of rounded pea-like grains of calcic carbonate held together by a calcareous cement. Travertine is the so-called "onyx marble" of Mexico and Arizona. It is a compact rock, concentric in structure, and formed by the precipitation of carbonate of lime from the waters of springs and streams.

[1] MERRILL, G. P., "Rocks, Rock Weathering, and Soils," pp. 104–114, 1897.

"Loose or unconsolidated rock débris of a prevailing siliceous nature comprise the sands, gravels, finer silts, and clays (laterite, adobe, loess, etc.). Shell sands and marls, on the other hand, are mainly calcareous, and are formed by an accumulation of the marine shells and of lime-secreting animals. Closely associated with the latter deposits in point of origin are the beds of diatomaceous or infusorial earth composed almost entirely of the siliceous casts of diatoms, a low order of seaweed or algæ.

"This unconsolidated material may pass by imperceptible gradations into representative rock types through simple processes of induration. Thus clay becomes shale, and that in turn slate, without necessarily changing the chemical or mineralogical composition of the original substance.

"Such terms as flagstone, freestone, brownstone, bluestone, graystone, etc., are generally given to sandstones of various colors and composition, while puddingstone, conglomerate, breccia, etc., apply to consolidated gravels and coarse feldspathic sands.

"The calcareous rocks are of many colors, according to the amount and character of the impurities present.

"**Metamorphic Rocks.**—Rocks of this class are such as have been produced by prolonged action of physical and chemical forces (heat, pressure, moisture, etc.) on both sedimentary and igneous rocks alike. The foliated types (gneiss, schist, etc.) represent an advanced stage of metamorphism on a large scale (regional metamorphism), and the peculiar schistose or foliated structure is due to the more or less parallel arrangement of their mineral components. The non-foliated types (quartzite, marble, slate, etc.) have resulted from the alteration of sedimentary rocks without materially affecting the structure and chemical composition of the original material.

"Rocks formed by contact metamorphism and hydration, such as hornfels pyroxene marble, serpentine, serpentineous limestone, etc., are of great interest from a petographical standpoint, but are rarely of importance as road materials.

"The color of metamorphic rock varies between gray and white of the purer marbles and quartzites to dark-grey and green of the gneiss, schists, and amphibolites. The green varieties are commonly known as greenstones, or greenstone schists."

Interpretation of Tests.—It has been found impractical to specify definite qualities of stone for use in macadam highways. Economy and practical engineering demand that all available sources be considered. Tests are made to determine the relative qualities of stone from these different sources and the results used as a guide for selection.

In the work of the New York State Highway Commission all tests are tabulated geographically, using a county as a unit. Table 21 is compiled from the records of this department. It will be

noted that comparisons are made in different classifications only, as it is considered that conclusions should not be drawn from a comparison of tests procured from materials having different origins and composed of different minerals.

For the purpose of ready comparison a figure known as the "weighted value" has been introduced (see last column of table). This is computed by giving relative weights of 3 to the French coefficient, 2 to the hardness, 1 to the toughness values, and adding three together. These relative weights were determined from a consideration of the amount of material used in the different tests and the personal equation of running them.

By consulting these tables, the available rocks of different classifications in various sections throughout New York State can be determined readily, and as new tests are completed they are compared with good average material from that section.

Conclusions.—Trap (diabase), granite, gneiss, quartzite, sandstone, and limestone are the most common rocks and when found in a good state of preservation make good surfacing materials (see Chap. VI, pp. 440 and 446, for acceptable test values, macadam top course stones).

As generally found, trap is uniform in hardness and toughness, making an excellent material for use in top course.

Granite and gneiss, where they occur with hornblende replacing a large percentage of the quartz, make an excellent surfacing stone.

Quartzites when found in a good state of preservation are hard and tough. They should not be confused with crystalline quartz which is hard but brittle.

Sandstones are extremely variable and only the better varieties should be used.

Limestones range from the fine-grained dense products which are hard and tough to the coarse-grained soft products which are not suitable for surfacing.

2. SCREENINGS

Screenings act as a filler and binder for water-bound macadam and as a partial filler for bituminous macadam. For use in water-bound construction the main mineral constituent is the most essential feature to be considered, as this must be a material that will form a binder and "puddle" readily when subjected to the action of a road roller and water.

Limestone screenings have proved the most efficient as a binder in water-bound construction, although trap and some other igneous rocks can be bound with their own dust by repeated puddling. Screenings consisting mainly of quartz have not been used successfully in water-bound construction except by the addition of some limestone screenings. The use of a percentage of clay or loam as a binder is not advisable except where the cost of limestone screenings would be prohibitive.

Laboratory methods for testing the cementing power of rock powders are available, but the results obtained are erratic and undependable.

In plain water-bound roads it is often necessary to mix some limestone screenings, fine sandy loam, or even a small percentage of clay loam with trap, granite, sandstone, quartzite, or gneiss screenings to get a good bond and prevent raveling in dry weather.

3. BOTTOM-COURSE MACADAM STONE

As the bottom stone simply spreads the wheel loads transmitted through the top course and is not directly subjected to the traffic action, almost any stone that breaks into cubical irregular shapes that will not air or water slake, and that is hard enough to stand the action of the roller during construction, will be satisfactory.

Any of the materials listed in Table 120, except shale and slate, can be used, provided they are not rotten from long exposure in the air. The different available varieties are usually tested in the same manner as for top stone in order to pick the best. Blast-furnace crushed slag makes an excellent bottom course but is not uniform enough for top course.

4. FILLERS

Fillers are used in the bottom course to fill the voids between the crushed stone and to prevent rocking or sidewise movement of the larger pieces.

They should be easy to manipulate in placing, should not soften when wet, or draw water up from the subgrade by capillary action.

The materials most used for macadam bottom are:

Coarse sandy loam.
Coarse sand.
Gravel with large excess of fine material.
Stone screenings.

The fitness of the material can be determined by inspection and by wetting a handful; if it gets sticky or works into a soft mud it should not be used.

Boulder or Telford Base Fillers.—This type of construction requires the use of clean, hard, gravel fairly coarse (at least 40% retained on ¼″ screen) with not over 15% of loam or silt content, or broken stone, slag, or chert. If broken stone is used, the voids of the stone must be filled with the same class of sand or screenings as stipulated for macadam bottom.

5. VITRIFIED BRICK

Bricks must withstand the same destructive agencies as described for top stone. They must be uniform in size, tough, hard, dense, evenly burned, and, on account of their peculiar shape, must have a high resistance against rupture. These properties are tested by the standard methods adopted by the American Brick Manufacturers' Association described below.

It should be understood that bricks suitable for paving are manufactured in a different way and of different materials than ordinary building bricks.

"The materials for molding any paving brick, must be of a peculiar character which will not melt and flow when exposed to an intense heat for a number of days but will gradually fuse and form vitreous combinations throughout while still retaining its form.

"The resulting brick must be a uniform block of dense texture in which the original stratification and granulation of the clay has been wholly lost by fusion which has stopped just short of melting the clay and forming glass.

"The clay while fusing must shrink equally throughout, thus causing the brick to be without laminations or of any exterior vitrified crust differing from the interior."[1]

The great majority of paving bricks are made in Ohio, Illinois, Indiana, Pennsylvania, West Virginia, and New York. They are classed as shale or fire-clay brick.

BRICK

"Paving brick shall be reasonably perfect in shape—shall be free from marked warping or distortion, and shall be uniform in size, so as to fit closely together and to make a smooth pavement. All brick shall be homogeneous in texture and free from laminations and seams. All brick shall be evenly burned and thoroughly vitrified.

"Soft, brittle, cracked, or spalled brick, or brick kiln marked to a height or depth of over $\frac{3}{64}''$ will be rejected.

"If brick have rounded corners, the radius shall not be greater than $\frac{1}{16}''$

"Brick must not have less than two nor more than four vertical lugs or projections not more than $\frac{1}{2}''$ wide, on one side of each brick, the total area of all lugs being not more than 3 sq. in., so that when laid there shall be a separation between the bricks of at least $\frac{1}{8}''$ and not more than $\frac{1}{4}''$. The imprint, or name of the brick, or maker, if used, shall not be by means of recessed, nor by raised letters. The two ends of the brick shall have a semicircular groove, with a radius of not less than $\frac{1}{8}''$ and not more than $\frac{1}{4}''$. Grooves shall be so located that when the bricks are laid together the grooves shall match perfectly; grooves shall be horizontal when brick is laid in pavement.

"All brick shall not be less than $3\frac{1}{4}$ by $3\frac{3}{4}$ by $8\frac{1}{2}''$ nor more than $3\frac{1}{2}$ by 4 by 9'' in size.

"All brick shall be subject to tests for abrasion and impact, for absorption according to the standard methods prescribed by the National Brick Manufactures' Association, as follows:

"The Rattler.—The machine shall be of good mechanical construction, self-contained, and shall conform to the following details of material and dimensions, and shall consist of barrel, frame, and driving mechanism as herein described.

"The Barrel.—The barrel of the machine shall be made up of the heads, headliners, and staves.

"The heads shall be cast with trunnions in one piece. The trunnion bearings shall not be less than $2\frac{1}{2}''$ in diameter or less than 6'' in length.

"The heads shall not be less than $\frac{3}{4}''$ thick nor more than $\frac{7}{8}''$. In outline they shall be a regular 14-sided polygon inscribed in a circle $28\frac{3}{8}''$ in diameter. The heads shall be provided with flanges not less than $\frac{3}{4}''$ thick and extending outward $2\frac{1}{2}''$ from the inside face of head to afford a means of fastening the staves. The flanges shall be slotted on the outer edge, so as to provide for two $\frac{3}{4}''$ bolts at each end of each stave, said slots to be $\frac{13}{16}''$ wide and $2\frac{3}{4}''$ center to center. Under each section of the flanges there shall be a brace $\frac{3}{8}''$ thick and extending down the outside of the head not less than 2''. Each slot shall be provided with recess for bolt head, which shall act to prevent the turning of same. There shall be for each head a cast-iron headliner 1'' in thickness and conforming to the outline of the head, but inscribed in a circle $28\frac{1}{8}''$ in diameter. This liner or wear plate shall be fastened to the head by seven $\frac{5}{8}''$ cap screws, through the head from the outside. These wear plates, whenever they become worn down $\frac{1}{2}''$ below their initial surface level, at any point of their surface, must be replaced with new. The metal of which these wear plates is to be composed shall be what is known as hard machinery iron, and must contain not less than 1 % of combined carbon. The faces of the polygon must be smooth and give uniform

[1] JUDSON, "Roads and Pavements," p. 87.

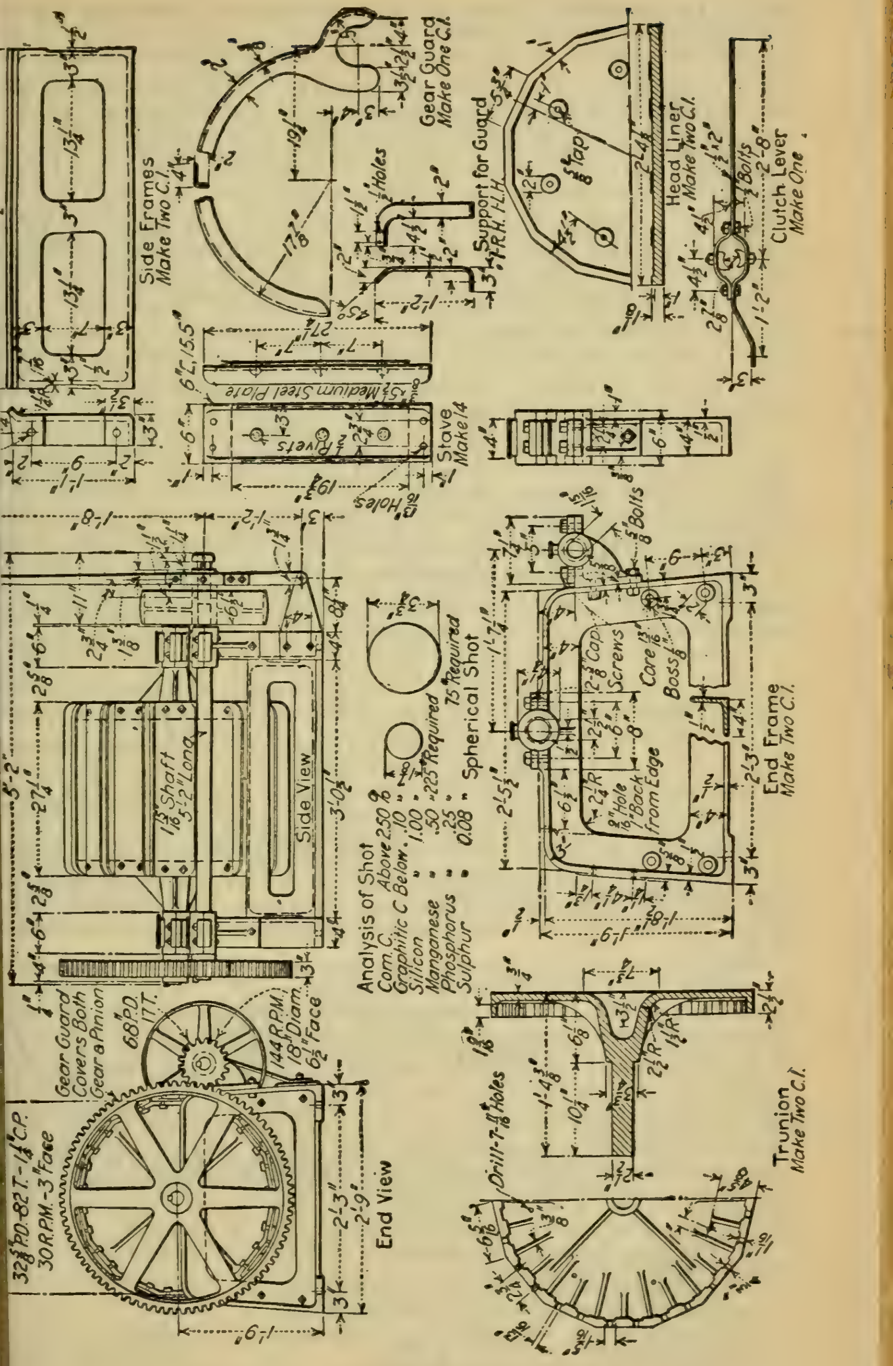


FIG. 257.—Details of brick rattler.

bearing for the staves. To secure the desired uniform bearing the faces of the head may be ground or machined.

"**The Staves.**—The staves shall be made of 6″ medium steel structural channels 27¼″ long and weighing 15.5 lb. per lineal foot.

"The channels shall be drilled with holes 13⁄16″ in diameter, two in each end, for bolts to fasten same to head, the center line of the holes being 1″ from either end and 1⅜″ either way from the longitudinal center line.

"The space between the staves will be determined by the accuracy of the heads, but must not exceed 5⁄16″. The interior or flat side of each channel must be protected by a lining or wear plate ⅜″ thick by 5½″ wide by 19¾″ long. The wear plate shall consist of medium steel plate, and shall be riveted to the channel by three ½″ rivets, one of which shall be on the center line both ways and the other two on the longitudinal center line and spaced 7″ from the center each way. The rivet holes shall be countersunk on the face of the wear plate and the rivets shall be driven hot and chipped off flush with the surface of the wear plate. These wear plates shall be inspected from time to time, and if found loose shall be at once riveted, but no wear plate shall be replaced by a new one except as the whole set is changed. No set of wear plates shall be used for more than 150 tests under any circumstances. The record must show the date each set of wear plates goes into service and the number of tests made upon each set.

"The staves when bolted to the heads shall form a barrel 20″ long, inside measurement, between wear plates. The wear plates of the staves must be so placed as to drop between the wear plates of the heads. These staves shall be bolted tightly to the heads by four ¾″ bolts, and each bolt shall be provided with lock nuts and shall be inspected at not less frequent intervals than every fifth test and all nuts kept tight. A record shall be made after each inspection, showing in what conditions the bolts were found.

"**The Frame and Driving Mechanism.**—The barrel should be mounted on a cast-iron frame of sufficient strength and rigidity to support same without undue vibration. It should rest on a rigid foundation and be fastened to same by bolts at not less than four points.

"It should be driven by gearing whose ratio of driver to driven should not be less than 1:4. The counter shaft upon which the driving pinion is mounted should not be less than 1 15⁄16″ in diameter, with bearings not less than 18″ in diameter and 6½″ in face. A belt of 6″ double-strength leather properly adjusted, so as to avoid unnecessary slipping, should be used.

"(As a part of this publication will be found a complete working drawing of a machine which will meet the above specifications and requirements.)

"**The Abrasive Charge.**—*a.* The abrasive charge shall consist of two sizes of cast-iron spheres. The larger size shall be 3¾″ in diameter when new approximately 7.5 lb. (3.40 kilos) each. Ten shall be used.

"These shall be weighed separately after each ten tests, and if the weight of any large shot falls to 7 lb. (3.175 kilos) it shall be discarded and a new one substituted; provided, however, that all of the large shot shall not be discarded and substituted by a new one at any single time, and that, so far as possible, the large shots shall compose a graduated series in various stages of wear.

"The smaller-size spheres shall be, when new, 1.875″ in diameter and shall weigh not to exceed 0.95 lb. (0.430 kilo) each. Of these spheres so many shall be used as will bring the collective weight of the large and small spheres most nearly to 300 lb., provided no small sphere shall be retained in use after it has been worn down so that it will pass a circular hole 1¾″ in diameter, drilled in a cast-iron plate ¼″ in thickness, or weigh less than 0.75 lb. (or 0.34 kilos). Further, the small spheres shall be tested by passing them over such an iron plate drilled with such holes, or shall be weighed after every ten tests, and any which pass through or fall below specified weight shall be replaced by new spheres, and provided, further that all of the small spheres shall not be rejected and replaced by new ones at any one time, and that so far as possible the small spheres shall compose a graduated series in various stages of wear. At any time that any sphere is found to be broken or defective it shall at once be replaced.

"*b.* The iron composing these spheres shall have a chemical composition within the following limits:

Combined carbon, not less than 2.50%.
Graphitic carbon, not more than 0.10%.
Silicon, not more than 1%.
Manganese, not more than 0.50%.
Phosphorus, not more than 0.25%.
Sulphur, not more than 0.08%.

"For each new batch of spheres used the chemical analysis must be furnished by the maker, or be obtained by the user, before introduction into the charge, and unless the analysis meets the above specifications the batch of spheres shall be rejected.

"The Brick Charge.—The number of brick per charge shall be ten for all bricks of the so-called "block size" whose dimensions fall between from 8 to 9″ in length, 3¾″ in breadth, and 3¾ and 4¼″ in thickness. No block should be selected for test that would be rejected by any other requirements for the specifications.

" The brick shall be clean and dried for at least 3 hrs. in a temperature of 100°F before testing,

"Speed and Duration of Revolution.—The rattler shall be rotated at a uniform rate of not less than 29½ nor more than 30½ r.p.m., and 1800 revolutions shall constitute the standard test.

"A counting machine shall be attached to the rattler for counting the revolutions. A margin of not to exceed ten revolutions will be allowed for stopping. One start and stop per test is regular and acceptable.

"The Results.—The loss shall be calculated in percentage of the original weight of the dried brick composing the charge. In weighing the rattled brick, any piece weighing less than 1 lb. shall be rejected.

"Records.—*a.* The operator shall keep an official book, in which the alternate pages are perforated for removal. The record shall be kept in duplicate, by use of a carbon paper between the first and second sheets, and when all entries are made and calculations are completed the original record shall be removed and the carbon duplicate preserved in the book. All calculations must be made in the space left for that purpose in the record blank, and the actual figures must appear. The record must bear its serial number and be filled out completely for each test, and all data as to dates of inspection and weighing of shot and replacement of worn-out parts must be carefully entered, so that the records remaining in the book are continuous. In event of further copies of a record being needed, they may be furnished on separate sheets, but in no case shall the original carbon copy be removed from the record book.

Report of Standard Rattler Test of Paving Bricks

Identification Data Serial (—)

Name of firm furnishing sample..
Name of firm manufacturing sample......................................
Street or job which sample represents....................................
Brands or marks on the brick...
Quantity furnished......................Drying treatment................
Date received...........................Date tested.....................
Length....................Breadth...............Thickness............

Standardization Data

Number of charges treated since last inspection..........................
Weight of charge (after standardization)..................................
Condition of locknuts on staves...
Condition of scales...
10 Large spheres................
Small spheres................
Total....................
Number of charges tested since stave linings were renewed
Repairs (note any repairs affecting the condition of the barrel)

Running Data

Time readings..........Revolution..............Running notes..........
Counter...............Stops, etc..............
Readings..............
Hours...... Minutes...... Seconds......
Beginning of test............
Final reading...............

Weights and Calculations

Initial weight of 10 bricks.............. Percentage loss...........
Final weight of same.................... (NOTE.—The calculation
Loss of weight.......................... must appear.)
Number of broken bricks and remarks on same
I certify that the foregoing test was made under the specifications of .... and is a true record.
Date............ Signature of (tester)...................
Location of laboratory...................

"Any brick which loses 24% or more in the rattler, or increases more than 3½% in weight or less than one-half of 1% in the absorption test will be rejected."

6. BITUMINOUS BINDERS

The subject of bitumens is an intricate one and the reader is referred to the works of Clifford Richardson, Prevost Hubbard, and others for detailed information, as a book of this character can give only an outline.

There are a number of dust preventives and road binders on the market which depend for their effectiveness on a bituminous-binding base. The term "bitumen" is applied to a great many substances. Hubbard arbitrarily defines bitumens as "consisting of a mixture of native or pyrogenetic hydrocarbons and their derivatives, which may be gaseous, liquid, a viscous liquid, or solid, but if solid, melting more or less readily upon the application of heat and soluble in chloroform, carbon bisulphide, and similar solvents."[1]

The bitumens may be classed as native and artificial. The native bituminous materials, that are used in road work, are the asphaltic and semiasphaltic oils (dust layers), Malthas (the binding base of rock asphalts), Trinidad, Bermudez California, and Cuba asphalts, gilsonite, and grahamite (which, however, are too brittle in their natural state and require fluxing with a suitable residual oil before they can be used as binders). The natural asphalts are refined to remove water and any objectionable amount of impurities by heating until the gases are driven off, skimming the vegetable matter which rises to the surface, and removing the mineral constituents which fall to the bottom.

The artificial bituminous materials are derived by the destructive distillation of coal, or by fractional distillation of crude coal tars, or the native petroleum oils. They comprise the crude coal and water-gas tars, the refined tars, the residual oils and semisolid binders derived from the petroleum oils. They vary greatly in consistency and binding power.

The tests and detailed requirements for light, medium, and heavy bitumens are given on pages 727 and 1388.

The following material is briefed from *Bulletin* 34, U. S. Office of Public Roads: The light oils and tars have a relative small percentage of bituminous base and are effective only so long as it retains its binding power; the more permanent binders contain a larger percentage of bitumen; these are the heavy oils and semisolids.

[1] "Dust Preventives and Road Binders," John Wiley & Sons, Inc.

ARTIFICIAL BITUMENS

Crude Tars.—Coke ovens and gas plants produce most of the coal ars in use. These tars contain various complex combinations of arbon, hydrogen, and oxygen and small amounts of nitrogen and ulphur. They vary in composition according to the material rom which they are made and the temperature at which they are listilled. The percentage of free carbon ranges from 5 to 35%, nd the bitumen from 60 to 95%, depending on the temperature of nanufacture. Tars produced at high temperatures contain free arbon in excess which weakens their binding power; they also ontain a large amount of anthracine and naphthalene, two useless naterials from the standpoint of road work. Tars produced at ow temperatures are to be preferred. Coke tar is low-temperature ar; gas tar is high-temperature tar.

ABLE 122.—SPECIFIC GRAVITY AND COMPOSITION OF TAR PRODUCTS. (*From Bulletin* 34, *U. S. Office of Public Roads*)

Kind of tar	Specific gravity	Ammoniacal water, %	Total light oils to 170°C., %	Total dead oils 170–270°C., %	Residue (by difference), %
Water-gas tar	1.041	2.4	21.6[a]	52.0[b]	24.0[c]
Crude coal tar	1.210	2.0	17.2[d]	26.0[e]	54.8[f]
Refined coal tar	1.177	0.0	12.8[b]	47.6[g]	39.6[f]

[a] Distillate, mostly liquid.
[b] Distillate, all liquid.
[c] Pitch, very brittle.
[d] Distillate, mostly solid.
[e] Distillate, one-half solid.
[f] Pitch, hard and brittle.
[g] Distillate, one-third solid.

Refined Tars.—Much of the road tar is refined tar—that is, has been subjected to fractional distillation to remove the valuble volatile compounds. The residuum from this process is a iick, viscous material known as coal-tar pitch, and if the crude ır from which it is obtained was produced at a low temperature it nearly pure bitumen; the dead oils obtained from the distillation re of little value and are often run back into the pitch, which makes liquid when cold. The accompanying table gives the approxiıate composition of water-gas tar, crude coal tar, and refined tar. If the tar is used as a temporary dust layer only, it should be ›w-temperature, dehydrated tar, liquid when cold. If used as a ıore permanent binder and applied hot, it should have a larger ercentage of pitch, should contain no water, and be free from an ccessive amount of free carbon. If used as a mastic in bituminous ıacadam, it should contain a high percentage of pitch and be free om the defects mentioned.

Natural Bitumens and Artificial Oils and Semi-solids.—Mineral ls can be classed as paraffin petroleums, mixed paraffin and asphalc petroleums, and asphaltic petroleums. The relative value of ls as a source of supply for road materials depends on their perntage of asphaltic residue. The eastern oils found in New York, ennsylvania, West Virginia, etc., are paraffin petroleums; the

western oils vary from light to heavy asphaltic petroleums, and th southern oils have a mixed paraffin and asphaltic base.

The crude petroleum is refined by fractional distillation to obtai its valuable products, such as kerosene, etc. The character c the residue depends, as for the tars, on the crude material and th method of manufacture; the operation, known as "cracking, which is used to increase the yield of the inflammable oils, produce an excess of free carbon.

The paraffin petroleum residuums are soft and greasy and ai not suitable for road work; they contain a large amount of the pai affin hydrocarbons and paraffin scale (crude paraffin).

The California petroleum residuums resemble asphalt, and carefully distilled without cracking should contain little or no fre carbon. They are suited to road work.

The Texas or semiasphaltic petroleums contain some paraff hydrocarbons and about 1% of paraffin scale. Residuums fro these oils, if containing a relatively small amount of paraffin, ca be successfully used.

The required properties of residuum binders used on the Ne Jersey State roads in 1922 are given (p. 1388).

The accompanying tables give a general idea of the relati characteristics of the crude petroleums and petroleum residuum

TABLE 123.—RESULTS OF TESTS OF CRUDE PETROLEUM. (*Fro Bulletin* 34, *U. S. Office of Public Roads*)

Kinds of oil	Specific gravity	Flash point, degrees centigrade	Volatility at 110°C. 7 hr., %	Volatility at 160°C. 7 hr., %	Volatility at 205°C. 7 hr., %	Residue, %
Pennsylvania, paraffin......	0.801	[a]	47.3	58.0	68.0	32.0[b]
Texas, semiasphaltic.......	0.904	43	20.0	27.0	49.0	51.0[c]
California, asphaltic........	0.939	26	....	....	42.7[d]	57.3[e]

[a] Ordinary temperature.
[b] Soft.
[c] Quick flow.
[d] Volatility at 200°, 7 hr.
[e] Soft maltha; sticky.

TABLE 124.—RESULTS OF PETROLEUM RESIDUUM

Kinds of oil	Specific gravity	Flash point, degrees centigrade	Volatility at 200°C. 7 hr., %	Residue, %	Solid paraffin, %	Fixed carbon, %
Pennsylvania, paraffin......	0.920	186	14.2	85.8[a]	11.0	3.[illegible]
Texas, semiasphaltic.......	0.974	214	6.2	93.8[a]	1.7	3.[illegible]
California, asphaltic........	1.006	191	17.3	82.7[a]	0.0	6.[illegible]

[a] Soft.

Tests of Bitumens and Their Significance.—Bitumens for use as he cementing material in road construction may, according to their ource and characteristics, be divided into the two general classes f asphalt and tars.

The asphalts suitable for use as the cementing agent in road onstruction are produced either by reducing asphaltic-base petro-um to a suitable consistency by the distillation process or by soften-ng the so-called solid asphalts to a suitable consistency by the ddition of flux produced by the partial distillation of petroleum.

The different grades, relative to consistency, of road oils are sually produced by the partial reduction of asphaltic-base etroleum.

By the destructive distillation of bituminous coals or the "crack-ng" of petroleum oils during the carburetting process in the manu-acture of water gas, crude tars are produced. These crude tars re refined or reduced by distillation to a suitable consistency or use in road construction.

Bitumens are used in road construction for the purpose of water-roofing the surface and adding to the mechanical bond of the ineral aggregate by cementing together the finer particles of ineral matter, thus preventing their displacement under the action f traffic and retaining them in the road surface where they fill e interstices between the larger stone and bind them together.

The desirable characteristics of bituminous material for road-uilding purposes are: (1) adhesiveness, (2) non-susceptibility to anges in temperature, and (3) stability or "life." The chief bject of bituminous material specifications is to make imperative ese desirable qualities of the material.

In testing bituminous materials it should be remembered at the laboratory results obtained in the different tests are largely r comparative purposes. By this means new or but-little-used aterials may be compared with materials which have proved tisfactory under service tests. Also laboratory results furnish n accurate means of specifying the exact characteristics of the aterial desired for any given purpose.

Adhesiveness.—The adhesiveness of the material is provided r in specifications by suitable requirements of ductility and ughness.

The ductility and toughness tests are made for the purpose of etermining the adhesive and binding qualities of the material nder different conditions of temperature. The ductility test is ade by determining the distance a briquette of the material, aving a cross-section 1 sq. cm. will draw before breaking. Since mperature affects the results, a standard temperature of 77°F. as been adopted generally for making this test. Experience aches that the greater the distance that a briquette of the material ll stretch out before breaking, the more sticky and adhesive the aterial. This test may be performed in a rough manner by pull-g out a small roll of the material between the fingers. Material hich will not pull out to a long thread before breaking is usually oken of as "short." Such materials are not adhesive or sticky d it is extremely difficult to bind a road with them, even under e most favorable circumstances.

As stated, the ductility test is usually made at a temperature o 77°F., and thus measures the adhesiveness of the material at a rather high temperature. To obtain an indication of the characte of the material at a low temperature the toughness test is made a a temperature of 32°F. This test is performed by dropping a weight of 2 kg. on a cylinder of the material 1¾″ in diameter by 1¾″ in height. The first height of the drop is usually from a distance of 5 cm. and is gradually increased until rupture of th cylinder occurs. A rough field test for toughness may be performe by noting whether a piece of the material will fracture under sharp blow. If the temperature of the material is about 32°F., th results will be more indicative of the character of the material.

Bitumens which are brittle or which give a low toughness result lose their binding value in cold weather and roads constructed b their use are apt to ravel and break up under traffic.

Bitumens which give good ductility and toughness results unde the methods outlined will give satisfactory results as the cementin medium when used in road construction, provided the other con struction details have been properly followed out.

In connection with the stickiness and adhesiveness of bitumens the fact should always be kept in mind that their purpose in roa construction as cementing medium is most effective when use with a hard, clean, dry mineral aggregate. As the departure from these qualities of the mineral aggregate increases so also the diffi culties are increased of getting a satisfactory road surface firml bound together.

Susceptibility to Changes in Temperature.—The susceptibilit to changes in temperature is shown by the relative hardness a indicated by the penetration tests at different temperatures, as a 32, 77, and 115°F.

The consistency of asphalts is referred to as the "penetration The penetration test is made by measuring the distance in hun dredths of a centimeter that a standard needle under a stated loa applied for a stated time, will penetrate into it vertically. Thes variable factors are usually as follows:

Needle: R. J. Roberts' Parabola "Sharps" No. 2

At 32°F. 200-g. weight, 1 min.
At 77°F. 100-g. weight, 5 sec.
At 115°F. 50-g. weight, 5 sec.

The material which is the most susceptible to changes in tem perature will show the greatest variation in penetration und varying conditions of temperature. Roads constructed by th use of materials which are extremely susceptible to changes temperature become soft in warm weather, mark easily, have tendency to rut, and become wavy. In cold weather this materi becomes very hard and slippery and is apt to be brittle and becom chipped from the road surface.

In addition to the general qualities of bitumens which are show by penetration tests, this test is used in specifications to defi within narrow limits the consistency of the material. The co sistency limits placed in specifications are governed by the clima

nd the type of construction to be followed, also the general size the mineral aggregate to be used. When the penetration method construction is followed it is necessary to use a relatively soft phalt in order that it may be incorporated in the road surface. the mixing types of construction a harder asphalt may be incorporated with the mineral aggregate. The use of a hard asphalt gether with a graded mineral aggregate gives a dense wearing rface that does not readily become wavy under traffic.

The information obtained by the penetration test is not readily ecked in the field without the aid of laboratory apparatus, but, a general rule, bitumens which are suitable for binders are plastic hen "worked" in the hands.

Stability.—When the term "stability" or "life" is used in reference to bitumens, it refers to the quality of the material by which it tains its characteristics over a long period of time. The laboratory tests which indicate this property are the evaporation test, e ratio of the penetration after evaporation to the original penetration, and the flash point.

The heating or evaporation test is made by placing 50 g. of the aterial in a flat-bottomed dish 2 3/16" in diameter by 1 3/8" in depth. his is placed in an oven maintained at specified temperature, ually 325°F., for a period of 5 hr.

This test may be considered as an accelerated test on the material. a binder, the percentage lost by weight together with the sulting hardening as shown by the relative penetration, *i.e.*, e ratio of the original penetration to the penetration after evaporation, are indicative of the "life" of the material. The less the aporation loss and the less the hardening as shown by the relative netration the greater will be the "life" of the material..

In an oil used for surface application the evaporation test shows e presence and quantity of light oils. This is indicative of the ne required for the oil to "set up" after application to the road rface, the evaporation from the large-surface area of the oil as plied to the road being roughly comparable with evaporation om the smallest surface area of the oil exposed at the higher nperature at which the test is made.

The open-flash test is made by heating at the rate of about 10°F. r minute a small quantity of the material, approximately 40 g., a dish of about the same size as the dish used for the penetration ts, 2 3/16" in diameter by 1 3/8" in depth. A small flame from a pillary tube is passed over the surface of the oil at each increase 5° in temperature.

A slight "puff" or explosion indicates the flash point has been ached. The presence of light oils or distillates is indicated by ow flash point. The flash point together with the evaporation ults give an indication as to the methods and materials used in e manufacture of the bitumen which is being tested.

Unless "cut-back" materials are being tested, in which an ceedingly light distillate as naphtha or benzole has been used the "cut-back" agent, considerable "smoke" will be given off m the sample before the flash point is reached. This feature ould be kept in mind when material is being heated for applica-

tion in the field. Material should never be heated in the field to point when it smokes profusely, for at such a temperature th material is being "burned" or hardened to such an extent that loses its adhesiveness and becomes brittle when cold, thus failing t become a binding or cementing agent which binds the miner aggregate of the road together.

The same "burning" effect on the material is produced by kee ing it at a temperature below the "smoking point" for a long peric (several hours) as would be produced at a higher temperatu for a shorter period of time. This important feature should alwa be kept in mind when heating material for application in the fiel

Such tests as those for water, specific gravity, purity, paraffi etc., are usually placed in specifications in addition to the tes which govern adhesiveness, non-susceptibility, and stability f the purpose of identification of materials used, methods of man facture, degree of refinement, and care used in refining.

The presence of water in bituminous materials causes frothi when heated to a temperature of about 212°F. In addition to t difficulty experienced in heating material containing water, d to the frothing an even application or distribution to the road such material is extremely difficult due to the presence of t froth, which is likely to be applied rather than the liquid bitume

Tests for specific gravity, purity, paraffin, etc., require labor tory apparatus to get results which indicate qualities of the materi The information obtained by these tests cannot be obtained l field tests.

If it is assumed that a suitable bitumen has been specified a obtained for construction work in which a bitumen is to serve the cementing material, the results obtained, relative to the bit men, will depend upon:

1. Not overheating (by high temperature or long time) t bitumen.

2. The use of hard, clean, dry stone.

3. Grading of the mineral aggregate to reduce voids and obta greater density.

4. Thorough and uniform incorporation of the bitumen wi mineral aggregate.

5. Maximum consolidation, by rolling when laid.

When bituminous materials which may be applied cold are be applied to a road surface, that surface should first be put in go condition. Surface application treatment is for the purpose preserving a road which is in good condition and not repairi an uneven road. A house is not repaired by painting it; rath the house is repaired and then painted, in order that it may rema in good condition. An attempt to build up a road-wearing surfa by the use of bitumens which may be applied cold usually resu in a surface which is easily marked, rutted, and pushed into wav

The following detailed description of "Recent Test Method for asphalts is quoted from Brochure 8, Asphalt Association:

Methods of Testing.—The following methods of testing are the to which reference is made in the specifications. Some of t descriptions have been condensed, but not changed in any essent particular.

SPECIFIC GRAVITY[1]

"**Pycnometer Method.**—The pycnometer (shown in Fig. 257*A*) consists of fairly heavy, straight-walled glass tube, 70 mm. long and 22 mm. in iameter, carefully ground to receive an accurately fitting solid glass stopper ith a hole of 1.6 mm. bore in place of the usual capillary opening. The wer part of this stopper is made concave in order to allow all air bubbles to scape through the bore. The depth of the cup-shaped depression is 4.8 mm. t the center. The stoppered tube has a capacity of about 24 cc. and when mpty weighs about 28 g.

"The clean, dry pycnometer is first weighed mpty and this weight is called *a*. It is then lled in the usual manner with freshly distilled ater at 25°C., and the weight is again taken and alled *b*. A small amount of the bitumen should e placed on a spoon and brought to a fluid con-ition by the gentle application of heat, with are that no loss by evaporation occurs. When ufficiently fluid, enough is poured into the dry ycnometer, which may also be warmed, to fill about half full, without allowing the material o touch the sides of the tube above the desired vel. The tube and contents are then allowed

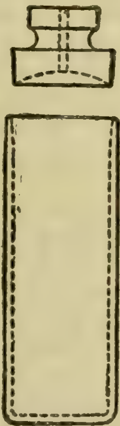


FIG. 257*A*.—Pycnometer (Hubbard type).

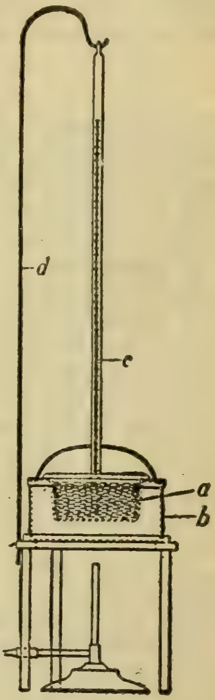


FIG. 257*B*.—Open-cup oil tester.

o cool to room temperature, after which the tube is carefully weighed with he stopper. This weight is called *c*. Distilled water at 25°C. is then poured until the pycnometer is full. After this the stopper is inserted, and the hole cooled to 25°C. by a 30-min. immersion in a beaker of distilled water aintained at this temperature. All surplus moisture is then removed with soft cloth, and the pycnometer and contents are weighed. This weight is alled *d*. From the weights obtained the specific gravity of the bitumen may e readily calculated by the following formula:

$$\text{Specific gravity } 25°\text{C.}/25°\text{C.} = \frac{c - a}{(b - a) - (d - c)}.$$

"The specific gravity of fluid bitumen may be determined in the ordinary anner with this pycnometer by completely filling it with the material and ividing the weight of the bitumen thus obtained by that of the same volume f water."

FLASH POINT[2]

"**Open-cup Method.**—The open-cup oil tester (shown in Fig. 257*B*), consts of a brass oil cup *a* of about 100-cc. capacity, and an outer vessel *b*

[1] *U. S. Dept. Agr., Bull.* 314, p. 5.
[2] *U. S. Dept. Agr., Bull.* 314, p. 17.

which serves as an air jacket; a suitable thermometer *c* is suspended from th wire support *d* directly over the center of the cup so that its bulb is entirel covered with asphalt but does not touch the bottom of the cup. The testir flame is obtained from a jet of gas passed through a piece of glass tubing, ar should be about 5 mm. in length.

"The test is made by first filling the oil cup with the material under exam nation to within about 5 mm. of the top. The Bunsen flame is then applie in such a manner that the temperature of the material in the cup is raised : the rate of 5°C. per minute. From time to time the testing flame is brougl almost in contact with the surface of the asphalt. A distinct flicker or flas over the entire surface of the asphalt shows that the flash point is reache and the temperature at this point is taken."

PENETRATION[1]

"**I. Definition.** 1. *Penetration.*—Penetration is defined as the consisten of a bituminous material expressed as the distance that a standard need vertically penetrates a sample of the material under known conditions loading, time, and temperature. When the conditions of test are not spec ically mentioned, the load, time, and temperature are understood to 100 g., 5 sec., 25°C. (77°F.), respectively, and the units of penetration indicate hundredths of a centimeter.

"**II. Apparatus.** 2. *Container.*—The container for holding the mater to be tested shall be a flat-bottom, cylindrical dish, 55 mm. (2$\frac{3}{16}$") diameter and 35 mm. (1$\frac{3}{8}$") deep.[2]

"3. *Needle.*—The needle[3] for this test shall be of cylindrical steel rod 50 mm. (2") long and having a diameter of 1.016 mm. (0.04") and turned on o end to a sharp point having a taper of 6.35 mm. ($\frac{1}{4}$").[4]

"4. *Water Bath.*—The water bath shall be maintained at a temperature n varying more than 0.1°C. from 25°C. (77°F.). The volume of water sh not be less than 10l and the sample shall be immersed to a depth of not le than 10 cm. (4") and shall be supported on a perforated shelf not less th 5 cm. (2") from the bottom of the bath.

"5. *Apparatus for Penetration.*—Any apparatus which will allow t needle to penetrate without appreciable friction, and which is accurate calibrated to yield results in accordance with the definition of penetrati will be acceptable.

"6. *Transfer Dish for Container.*—The transfer dish for container shall a small dish or tray of such capacity as will insure complete immersion of t container during the test. It shall be provided with some means which w insure a firm bearing and prevent rocking the container.

"**III. Preparation of Sample.** 7. *Preparation of Sample.*—The samp shall be completely melted at the lowest possible temperature and stirr thoroughly until it is homogeneous and free from air bubbles. It shall th be poured into the sample container to a depth of not less than 15 mm. ($\frac{5}{8}$" The sample shall be protected from dust and allowed to cool in an atmosphe not lower than 18°C. (65°F.) for 1 hr. It shall then be placed in the wat bath along with the transfer dish and allowed to remain 1 hr.

"**IV. Testing.** 8. *Testing.*—*a.* In making the test the sample shall placed in the transfer dish filled with water from the water bath of sufficie depth to cover the container completely. The transfer dish containing t sample shall then be placed upon the stand of the penetration machir The needle, loaded with specified weight, shall be adjusted to make conta with the surface of the sample. This may be accomplished by making co tact of the actual needle point with its image reflected by the surface of t sample from a properly placed source of light. Either the reading of t dial shall then be noted or the needle brought to zero. The needle is th released for the specified period of time, after which the penetration machi is adjusted to measure the distance penetrated.

"At least three tests shall be made at points on the surface of the samp not less than 1 cm. ($\frac{3}{8}$") from the side of the container and not less th 1 cm. ($\frac{3}{8}$") apart. After each test the sample and transfer dish shall returned to the water bath and the needle shall be carefully wiped towa

[1] Amer. Soc. Testing Materials, Standard Test D5-16.

[2] This requirement is fulfilled by the American Can Co.'s gill-style oir ment box, deep pattern, 3-oz. capacity.

[3] *J. Agr. Research*, vol. 5, 24, pp. 1125–1126.

[4] No. 2 Roberts sewing needle which has been carefully checked with standard needle may be used.

point with a clean, dry cloth to remove all adhering bitumen. The ported penetration shall be the average of at least three tests whose values all not differ more than four points between maximum and minimum.

"*b*. When desirable to vary the temperature, time, and weight and in der to provide for a uniform method of reporting results when varia- ns are made, the samples shall be melted and cooled in air as above ected. They shall then be immersed in water or brine, as the case may quire, for 1 hr. at the temperature desired. The following combinations e suggested:

"At 0°C. (32°F.), 200-g. weight, 60 sec.

"At 46.1°C. (115°F.), 50-g. weight, 5 sec."

DUCTILITY[1]

"A briquette of the material to be tested shall be formed by pouring the lten material into a briquette mold. The dimensions of the briquette ll be: 1 cm. (0.394″) in thickness throughout its entire length; distance tween the clips or end pieces, 3 cm. (1.181″); width of asphalt-cement tion at mouth of clips, 1 cm. (0.394″). The center pieces are removable, briquette mold being held together during molding with a clamp or wire.

"The molding of the briquette shall be done as follows: The two center tions shall be well amalgamated to prevent the asphalt cement from hering to them, and the briquette mold shall then be placed on a freshly algamated brass plate. The asphalt cement to be tested, while in a lten state, shall be poured into the mold, a slight excess being added to ow for shrinkage on cooling. When the asphalt cement in the mold is rly cool, the briquette shall be cut off level, with a warm knife or spatula. en it is thoroughly cooled to the temperature at which it is desired to ke the test, the clamp and the two side pieces are removed, leaving the quette of asphalt cement held at each end by the ends of the mold, which w play the part of clips. The briquette shall be kept in water for 30 n. at 4°C. (39°F.) or 25°C. (77°F.) before testing, dependent on the tem- ature at which the ductility is desired. The briquette and the clips ached shall then be placed in a ducility-test machine filled with water at of the above temperatures to a sufficient height to cover the briquette less than 50 mm. (1.969″). This machine consists of a rectangular ter-tight box, having a movable block working on a worm-gear from left right. The left clip is held rigid by placing its ring on a short metal peg vided for this purpose; the right clip is placed over a similar rigid peg the movable block. The movable block is provided with a pointer which ves along a centimeter scale. Before starting the test, the centimeter le is adjusted to the pointer at zero. Power is then applied by the rm gear pulling from left to right at the uniform rate of 5 cm. (1.969″) minute. The distance, in centimeters, registered by the pointer on the le at the time of rupture of the thread of asphalt cement shall be taken the ductility of the asphalt cement."

VOLATILIZATION TEST[2]

The oven shown in Fig. 257*C*, known as the New York testing laboratory n, is used by the Bureau of Public Roads, although any other form may used that will give a uniform temperature throughout all parts where nples are placed. The bulb of one of the thermometers is immersed in a nple of some fluid, non-volatile bitumen, while the other is kept in air at same level. The first thermometer serves to show the temperature of samples during the test, while the latter gives prompt warning of any den changes in temperature due to irregularities in the gas pressure, etc.

Before making the test the interior of the oven should show a tempera- e of 163°C. as registered by the thermometer in air. A round tin box cm. in diameter and 3½ cm. deep is accurately weighed after carefully ing with a towel to remove any grease or dirt. About 50 g. of the material e tested is then placed in the box. The material may then be weighed rough balance, if one is at hand, after which the accurate weight, which ld not vary more than 0.2 g. from the specified amount, is obtained. ay be necessary to warm some of the material in order to handle it con-

Trans. Am. Soc. Civil Eng., vol. 82, p. 1460, 1918.
U. S. Dept. Agr., Bull. 314, p. 19.

veniently, after which it must be allowed to cool before determining th accurate weight.

"The sample should now be placed in the oven, where it is allowed t remain for a period of 5 hr., during which time the temperature as shown b the thermometer in bitumen should not vary at any time more than 2°(from 163°C. The sample is then removed from the oven, allowed to cool, ar reweighed. From the difference between this weight and the total weig! before heating the percentage of loss on the amount of material taken calculated.

"Highly volatile and non-volatile materials should not be subjecte to this test at the same time in the same oven, owing to a tendency on tl part of the latter to absorb some of the volatile products of the former.

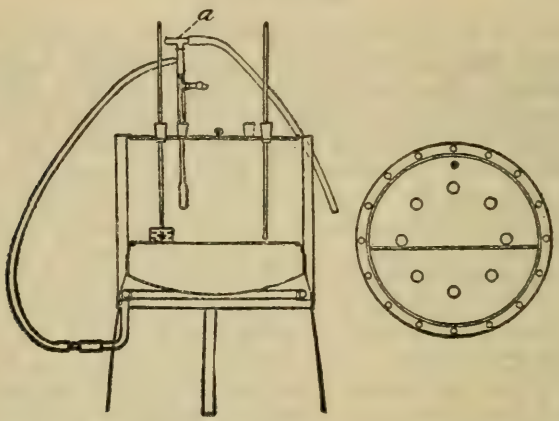


FIG. 257*C*.—New York testing laboratory oven.

"Some relative idea of the amount of hardening which has taken pl. may be obtained from the results of a float or penetration test made on residue, as compared with the results of the same tests on the original samp Before any tests are made on the residue, it should be melted and thoroug stirred while cooling."

TOTAL BITUMEN[1]

"**Gooch Crucible Method.**—This test consists in dissolving the bitum in carbon disulphide and recovering any insoluble matter by filtering solution through an asbestos felt. The form of Gooch crucible best adap for the determination is 4.4 cm. wide at the top, tapering to 3.6 cm. at bottom, and is 2.5 cm. deep.

"For preparing the felt, the necessary apparatus is arranged as shown Fig. 4, in which *a* is the filtering flask, *b* a rubber stopper, *c* the filter tu and *d* a section of rubber tubing which tightly clasps the Gooch crucibl The asbestos is cut with scissors into pieces not exceeding 1 cm. in leng after which it is shaken up with just sufficient water to pour easily. The c cible is filled with the suspended asbestos, which is allowed to settle fo few moments. A light suction is then applied to draw off all the water leave a firm mat of asbestos in the crucible. More of the suspended mate is added, and the operation is repeated until the felt is so dense that it scarc transmits light when held so that the bottom of the crucible is between eye and the source of light. The felt should then be washed several tir with water and drawn firmly against the bottom of the crucible by increased suction. The crucible is removed to a drying oven for a minutes, after which it is ignited at red heat over a Bunsen burner, coolec a desiccator, and weighed.

"From 1 to 2 g. of the bituminous material is now placed in the Erl meyer flask, which has been previously weighed, and the accurate wei of the sample is obtained. One hundred cubic centimeters of chemic

[1] *U. S. Dept. Agr., Bull.* 314, p. 25.

ure carbon disulphide is poured into the flask in small portions, with con-nual agitation, until all lumps disappear and nothing adheres to the ottom. The flask is then corked and set aside for 15 min.

"After being weighed, the Gooch crucible containing the felt is set up over ne dry pressure flask, as shown in the figure, and the solution of bitumen carbon disulphide is decanted through the felt without suction by gradually lting the flask, with care not to stir up any precipitate that may have settled ut. At the first sign of any sediment coming out, the decantation is stopped nd the filter allowed to drain. A small amount of carbon disulphide is then ashed down the sides of the flask, after which the precipitate is brought pon the felt nd the flask scrubbed, if necessary, with a feather or 'police-nan,' to remove all adhering material. The contents of the crucible are ashed with carbon disulphide, until the washings run colorless. Suction then applied until there is practically no odor of carbon disulphide in the ucible, after which the outside of the crucible is cleaned with a cloth mois-ned with a small amount of the solvent. The crucible and contents are ried in a hot-air oven at 100°C. for about 20 min., cooled in a desiccator, and eighed. If any appreciable amount of insoluble matter adheres to the ask, it should also be dried and weighed, and any increase over the original eight of the flask should be added to the weight of insoluble matter in

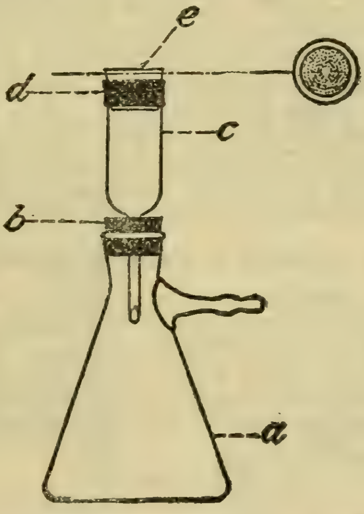


FIG. 257*D*.—Apparatus for determining soluble bitumen.

e crucible. The total weight of insoluble material may include both ganic and mineral matter. The former, if present, is burned off by igni-on at a red heat until no incandescent particles remain, thus leaving the ineral matter or ash, which can be weighed on cooling. The difference tween the total weight of material insoluble in carbon disulphide and the eight of substance taken equals the total bitumen, and the percentage eights are calculated and reported as total bitumen, and organic and organic matter insoluble, on the basis of the weight of material taken for alysis.

"This method is quite satisfactory for most asphalts, but where certain ke asphalts are present it will be found practically impossible to retain all the finely divided mineral matter on an asbestos felt. It is, therefore, nerally more accurate to obtain the result for total mineral matter by rect ignition of a 1-g. sample in a platinum crucible. The total bitumen is en determined by deducting from 100% the sum of the percentages of tal mineral matter and organic matter insoluble. If the presence of a rbonate mineral is suspected, the percentage of mineral matter may be ost accurately obtained by treating the ash from a fixed-carbon deter-

mination with a few drops of ammonium carbonate solution, drying at 100°C then heating for a few minutes at a dull-red heat, cooling, and weighing agai

When difficulty in filtering is experienced—for instance, when Trinid asphalt is present in any amount—a period of longer subsidence than 15 mi is necessary, and the following method proposed by the Committee Standard Tests for Road Materials of the American Society for Testi Materials is recommended.[1]

"From 2 to 15 g. (depending on the richness in bitumen of the substanc is weighed into a 150-cc. Erlenmeyer flask, the tare of which has be previously ascertained, and treated with 100 cc. of carbon disulphide. T flask is then loosely corked and shaken from time to time until practical all large particles of the material have been broken up, when it is set asi and not disturbed for 48 hr. The solution is then decanted off in a simil flask that has been previously weighed, as much of the solvent being pour off as possible without disturbing the residue. The first flask is aga treated with fresh carbon disulphide and shaken as before, when it is p away with the second flask and not disturbed for 48 hr.

"At the end of this time the contents of the two flasks are carefu decanted off upon a weighed Gooch crucible fitted with an asbestos filt the contents of the second flask being passed through the filter first. T asbestos filter shall be made of ignited long-fiber amphibole, packed in t bottom of a Gooch crucible to the depth of not over $\frac{1}{8}''$. After passi the contents of both flasks through the filter, the two residues are shaken wi more fresh carbon disulphide and set aside for 24 hr. without disturbi or until it is seen that a good subsidation has taken place, when the solve is again decanted off upon the filter. This washing is continued until t filtrate or washings are practically colorless.

"The crucible and both flasks are then dried at 125°C. and weigh The filtrate containing the bitumen is evaporated, the bituminous resid burned, and the weight of the ash thus obtained added to that of the resi in the two flasks and the crucible. The sum of these weights deduc from the weight of substance taken gives the weight of bitumen extracte

BITUMEN SOLUBLE IN CARBON TETRACHLORIDE[2]

"**Gooch Crucible Method.**—This determination is made in exactly same manner as described under Total Bitumen, using carbon tetrachlor as a solvent instead of carbon disulphide.

"The percentage of bitumen soluble is reported upon the basis of to bitumen taken as 100. Thus if the percentage soluble in carbon tet chloride should be found to be 98.5% and the percentage soluble in car disulphide 99.0% the percentage of total bitumen soluble in carbon tet chloride would be

$$\frac{98.5}{99.0} = 99.6\%."$$

MELTING POINT[3]

"**Ring and Ball Method.**—1. The softening of bituminous materi generally takes place at no definite moment or temperature. As the te perature rises, they gradually and imperceptibly change from a brittle exceedingly thick and slow-flowing material to a softer and less visc liquid. For this reason the determination of the softening point must made by a fixed, arbitrary, and closely defined method if the results obtai are to be comparable.

"**I. Apparatus.**—2. The apparatus shall consist of the following:

"*Ring.—a.* A brass ring 15.875 mm. ($\frac{5}{8}''$) inside diameter and 6.35 m ($\frac{1}{4}''$) deep; thickness of wall, 2.38 mm. ($\frac{3}{32}''$); permissible variation inside diameter and thickness of ring, 0.25 mm. (0.01''). This ring shall attached in a convenient manner to a No. 15 B. & S. gage brass wire (dia eter 1.79 mm. = 0.0703'') (see Fig. 257*E*).

"*b.* A steel ball 9.53 mm. ($\frac{3}{8}''$) in diameter weighing between 3.45 3.55 g.

[1] *Proc. Am. Soc. Testing Materials*, vol. 9, p. 221, 1909.
[2] *U. S. Dept. Agr., Bull.* 314, p. 30.
[3] Am. Soc. Testing Materials, Standard Method D36-19.

"*Container.*—*c.* A glass vessel, capable of being heated, not less than 9 n. (3.54″) in diameter by 13 cm. (5.12″) deep. (A 600-cc. beaker. Griffin w form meets this requirement.)

"*Thermometer.*—*d.* A thermometer which shall conform to the following ecifications:

Total length, 370–400 mm. (14.57–15.75″).
Diameter, 6.5–7.5 mm. (0.256–0.295″).
Bulb length, not over 14 mm. (not over 0.55″).
Bulb diameter, 4.5–5.5 mm. (0.177–0.217″).

"The scale shall be engraved upon the stem of the thermometer, shall be ear cut and distinct, and shall run from 0 to 80°C. (32 to 176°F.) in ⅕°C

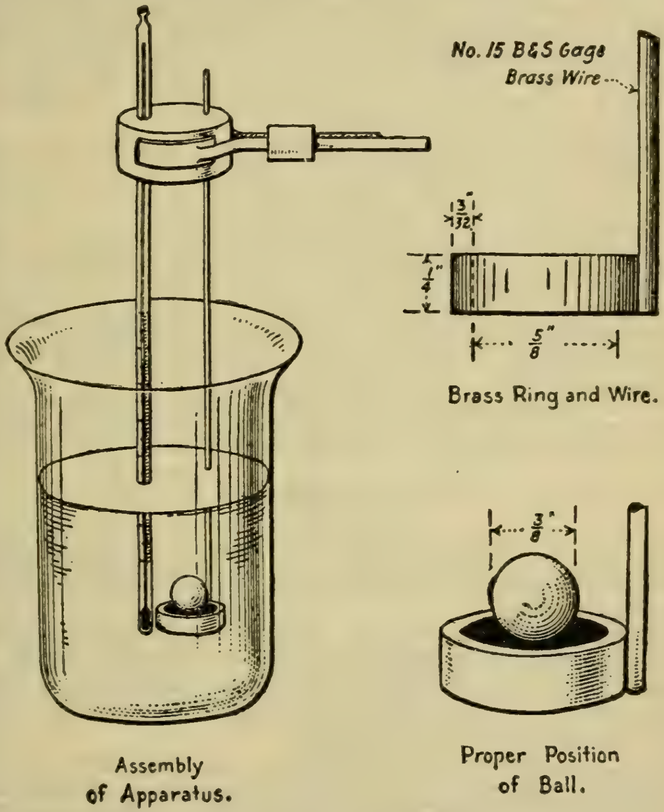


Fig. 257*E*.—Ring and ball apparatus.

visions. It shall commence not less than 7.5 cm. (2.95 in.) above the bottom the bulb. The thermometer shall be furnished with an expansion chamr at the top and have a ring for attaching tags. It shall be made of a itable quality of glass and be so annealed as not to change its readings der conditions of use. It shall be correct to 0.25°C. (0.45°F.) as deterined by comparison at full immersion with a similar thermometer caliated at full immersion by the U. S. Bureau of Standards.

Preparation of Sample

"**II. Preparation of Sample.**—3. The sample shall be melted and stirred oroughly, avoiding incorporating air bubbles in the mass, and then poured to the ring so as to leave an excess on cooling. The ring, while being filled,

should rest on a brass plate which has been amalgamated to prevent th bituminous material from adhering to it. After cooling, the excess materia should be cut off cleanly with a slightly heated knife.

"III. Testing.—*a.* Bituminous materials having softening points 90°C (194°F.) or below.

"*Assembling.*—4. Assemble the apparatus as shown in Fig. 5. Fill th glass vessel to a depth of substantially 8.25 cm. (3.25″) with freshly boile distilled water at 5°C. (41°F.). Place the ball in the center of the upp surface of the bitumen in the ring and suspend it in the water so that th lower surface of the filled ring is exactly 2.54 cm. (1″) above the bottom the glass vessel and its upper surface is 5.08 cm. (2″) below the surface the water. Allow it to remain in the water for 15 min. before applying hea Suspend the thermometer so that the bottom of the bulb is level with th bottom of the ring and within 0.635 cm. (¼″), but not touching, the ring.

"*Heating.*—5. Apply the heat in such a manner that the temperature the water is raised 5°C. (9°F.) each minute.

"*Softening Point.*—6. The temperature recorded by the thermomet at the instant the bituminous material touches the bottom of the glass vess shall be reported as the softening point.

"*Permissible Variation in Rise of Temperature.*—7. The rate of rise temperature shall be uniform and shall not be averaged over the period the test. The maximum permissible variation for any minute period aft the first three shall be ±0.5°C. (0.9°F.). All tests in which the rate of ri in temperature exceeds these limits shall be rejected.

"*b.* Bituminous materials having softening points above 90°C. (194°F

"*Modification for Hard Materials.*—8. Use the same method as given und (*a*) except that glycerin shall be used instead of water.

"IV. Accuracy.—9. The limit of accuracy of the test is ±0.5°C. (0.9°F

"V. Precautions.—10. The use of freshly boiled, distilled water is esse tial, as otherwise air bubbles may form on the specimen and affect t accuracy of the results. Rigid adherence to the prescribed rate of heati is absolutely essential to secure accuracy of results.

"A sheet of paper placed on the bottom of the glass vessel and co veniently weighted will prevent the bituminous material from sticking the glass vessel, thereby saving considerable time and trouble in cleaning

7. CEMENT

There are five different classes of cement—Portland, natur Puzzolan, iron-ore, and magnesia cements. Of these the Portla is usually specified.

Portland cement is the term applied to the finely pulveriz product resulting from the calcination to incipient fusion of intimate mixture of properly proportioned argillaceous and ca careous materials, and to which no addition greater than 3% h been made subsequent to calcination.[1]

Natural cement is the term applied to the finely pulverized pro uct resulting from the calcination of an argillaceous limestone at temperature only sufficient to drive off the carbonic acid ga

Portland cements are usually heavier, stronger, slower settir and more uniform than the natural cements and are generally us for road structures, such as culverts, retaining walls, etc. Po land cement is practically the only cement used to any extent the United States at the present time. The few manufacture of natural cement who were retaining a hold on the market sor few years back when the production of Portland cement was expe sive are finding it difficult to compete with this latter product its present price and quality.

[1] Am. Soc. Testing Materials, p. 353, 1915.
[2] *Ibid.*, p. 352, 1915.

The following is the standard specification for Portland cement as adopted by the American Society of Civil Engineers and the American Society for Testing Materials:

"**First: Specific Gravity.**—The specific gravity of cement shall not be less than 3.10. Should the test of cement as received fall below this requirement, a second test may be made upon a sample ignited at a low red heat. The loss in weight of the ignited cement shall not exceed 4%.

"**Second: Fineness.**—It shall leave by weight a residue of not more than % on the No. 100, and not more than 25% on the No. 200 sieve.

"**Third: Time of Setting.**—It shall not develop initial set in less than 30 min.; and must develop hard set in not less than 1 hr. nor more than 10 hr.

"**Fourth: Tensile Strength.**—The minimum requirements for tensile strength for briquettes 1 sq. in. in cross-section shall be as follows, and the cement shall show no retrogression in strength within the periods specified:

NEAT CEMENT

Age	Strength, pounds
24 hr. in moist air	175
7 days (1 day in moist air, 6 days in water)	500
28 days (1 day in moist air, 27 days in water)	600
1 PART CEMENT 3 PARTS STANDARD OTTAWA SAND	
7 days (1 day in moist air, 6 days in water)	200
28 days (1 day in moist air, 27 days in water)	275

"**Fifth: Constancy of Volume.**—Pats of neat cement about 3″ in diameter, ½″ thick at the center, and tapering to a thin edge shall be kept in moist air for a period of 24 hr.

"*a.* A pat is then kept in air at normal temperature and observed at intervals for at least 28 days.

"*b.* Another pat is kept in water maintained as near 70°F. as practicable, and observed at intervals for at least 28 days.

"*c.* A third pat is exposed in any convenient way in an atmosphere of steam, above boiling water, in a loosely closed vessel for 5 hr.

"These pats, to pass the requirements satisfactorily, shall remain firm and hard, and show no signs of distortion, checking, cracking, or disintegrating.

"**Sixth: Chemical Composition.**—The cement shall not contain more than .75% of anhydrous sulphuric acid (SO_2), nor more than 4% of magnesia (MgO)."

The equipment used in testing cement is standardized in detail and can be obtained in the Year Book published by the American Society for Testing Materials or Committee Report on Uniform Tests of Cement of the American Society of Civil Engineers, 1922.

CONCRETE MATERIALS. 8. FINE AGGREGATE

Fine aggregate for use in cement or asphaltic concrete should consists of sand free from any deleterious matter. Any sand which shows a coating on the grains should not be used until satisfactorily cleansed by washing.

The following tests are made on sand to determine its suitability for use in different classes of concrete:

1. Gradation.[1]
2. Percentage of voids.
3. Percentage of loam or silt.
4. Organic impurities.
5. Resistance to abrasion.
6. Compressive or tensile strength in cement mortar.

Mechanical Analysis of Aggregate.

TABLE 125.—AMERICAN SOCIETY FOR TESTING MATERIALS STAN[D]ARD SIEVES

Mesh designation	Unit of measure	Actual mesh	Opening	Wire diameter	Permissible variations: Mesh	Permissible variations: Diamete[r]
10[a]	Centimeter	3.9	0.200	0.056	0.04	0.005
	Inches	9.9	0.079	0.022	0.1	0.002
20[a]	Centimeter	8.0	0.085	0.040	0.2	0.0015
	Inches	20.3	0.0335	0.0157	0.5	0.0006
30	Centimeter	12.0	0.050	0.033	0.4	0.0012
	Inches	30.5	0.0197	0.0130	1.0	0.0005
40[a]	Centimeter	16.0	0.036	0.026	0.6	0.0010
	Inches	40.6	0.0142	0.0102	1.5	0.0004
50	Centimeter	20.0	0.029	0.021	0.8	0.0010
	Inches	50.8	0.0114	0.0083	2.0	0.000[illegible]
80	Centimeter	31.0	0.017	0.015	1.0	0.0008
	Inches	78.7	0.0067	0.0059	3.0	0.000[illegible]
100[a]	Centimeter	39.0	0.014	0.0116	1.0	0.0008
	Inches	99.1	0.0055	0.0046	3.0	0.000[illegible]
200[a]	Centimeter	79.0	0.0074	0.0053	3.0	0.0005
	Inches	200.7	0.0029	0.0021	8.0	0.000[illegible]

[a] It is recommended that for routine tests except for fine aggregate for h[ot] mixed, bituminous surfaces, the ¼″ screen and these sieves be used.

STANDARD METHOD FOR MAKING A MECHANICAL ANALYS[IS] OF SAND OR OTHER FINE HIGHWAY MATERIAL[2]

Adopted, 1919. Revised 1916, 1918.

"The method shall consist of drying at not over 110°C. (230°F.) to a co[n]stant weight of a sample weighing of from 100 to 500 g.; passing the samp[le] through each of the mesh sieves (American Society for Testing Materi[als] standard sieves) specified in Table 125;[3] determining the percentage [by] weight retained on each sieve, the sifting being continued on each sieve un[til] less than 1% of the weight retained on each sieve shall pass through the sie[ve] during the last minute of sifting; and recording the mechanical analy[sis] in the following manner:

Passing 200-mesh sieve.............................. ......
Passing 100- and retained on a 200-mesh sieve.................. ......
Passing 80- and retained on a 100-mesh sieve.................. ......
Passing 50- and retained on a 80-mesh sieve.................. ......

100.00

[1] For the effect of size and gradation on strength of concrete see pp. 479 484, Abram's "Fineness Modulus."

[2] Amer. Soc. Testing Materials, Standard Method, Serial Designatio[n] D7-18, slightly modified.

[3] NOTE.—The order in which the sieves are to be used in the process [of] sifting is immaterial and shall be left optional, but in reporting results t[he] order in which the sieves have been used shall be stated.

MAKING A MECHANICAL ANALYSIS OF MIXTURES OF SAND OR OTHER FINE MATERIAL WITH BROKEN STONE, BROKEN SLAG, OR GRAVEL PEBBLES[1]

"The method shall consist of drying at not over 110°C. (230°F.) to a constant weight a sample weighing in pounds six times the diameter in inches of the largest holes required; separating the sample by the use of a screen having circular openings 0.64 cm. (¼″) in diameter; examining the portion retained on the screen in accordance with the Standard Method for Making a Mechanical Analysis of Broken Stone or Broken Slag, except for Aggregates Used in Cement Concrete (Serial Designation: D18) of the American Society for Testing Materials; examining the portion passing this screen in accordance with the Standard Method for Making a Mechanical Analysis of Sand or Other Fine Highway Material, except for Fine Aggregates of Sand or Other Fine Highway Material, except for Fine Aggregates Used in Cement Concrete (Serial Designation D7) of the American Society for Testing Materials; and recording the mechanical analysis in the following manner:

Passing 200-mesh sieve	...... %
Passing 100- and retained on a 200-mesh sieve	...... %
Passing 80- and retained on a 100-mesh sieve	...... %
Passing 20- and retained on 80-mesh	...... %
Passing 10- and retained on a 20-mesh sieve	...... %
Passing 0.64-cm. (¼″) and retained on a 10-mesh sieve	...... %
Passing 1.27-cm. (½″) and retained on a 0.64-cm. (¼″) screen	...... %
Passing 1.90-cm. (¾″) and retained on a 1.27-cm. (½″) screen	...... %
	100.00%"

Tests for Loam. *Field Test.*—It is convenient to have a graduated tube but any tall bottle will do. Fill bottle or tube about one-third or half full of sand to be tested. Add water till bottle or tube is nearly full. Stopper the top, turn into a horizontal position and shake vigorously. Change quickly to vertical position and leave for 24 hr. without disturbing. The clay and loam will settle on top in more or less clearly defined degree, the amount of which can be easily measured. This method is sufficiently close for check field tests. The Standard laboratory test is described below.

"**Test for Amount of Clay and Silt in Sand or Fine Aggregate.**—The sample as received shall be moistened and thoroughly mixed, then dried to constant weight at a temperature between 100°C. (212°F.) and 110°C. (230°F.).

"Five hundred grams representative of the dried sample shall be placed in a dried and accurately weighed pan or vessel having vertical sides and provided with a pouring lip. This pan shall be substantially 22.9 cm. (9″) in diameter by not less than 10.2 cm. (4″) deep. Pour sufficient water in the pan to cover the same (about 225 cc.). Agitate vigorously for 15 sec. and then pour off the water into a tared evaporating dish, taking care not to pour off any sand. Repeat until the wash is clear, using a glass rod to stir the material for the last few washings.

"Thoroughly dry the pan and washed sand in an oven at between 100°C. (212°F.) and 110°C. (230°F.), weigh and determine net weight of sand.

"Compute the per cent of clay and silt as follows:

$$\frac{\text{Original weight} - \text{weight after washing}}{\text{Original weight}} \times 100 = \text{per cent of clay and silt.}$$

"For a check on the results, evaporate the wash water to dryness and weigh the residue.

$$\frac{\text{Weight of residue}}{\text{Original weight}} \times 100 = \text{per cent of clay and silt.}$$

[1] Amer. Soc. Testing Materials, Standard Method, Serial Designation: D19-16.

"**Test for Amount of Clay and Silt in Gravel.**—The sample as received shall be moistened and thoroughly mixed, then dried to constant weight at a temperature between 100°C. (212°F.) and 110°C. (230°F.).

"A representative portion of the dry material, weighing not less than fifty times the weight of the largest stone in the sample, shall be selected from the sample and placed in a dried and accurately weighed pan or vessel. The pan shall be 30.2 cm. (12") in diameter by not less than 10.2 cm. (4") deep, so nearly as may be obtained. Pour sufficient water in the pan to cover the gravel and agitate vigorously for 15 sec., using a trowel or stirring rod. Allow to settle for 15 sec., and then pour off the water into a tared evaporating dish, being careful not to pour off any sand. Repeat until the wash water is clear.

"Dry the washed material to constant weight in an oven at between 100°C. (212°F.) and 110°C. (230°F.), weigh and determine net weight of gravel.

"Compute the per cent of clay and silt as follows:

$$\frac{\text{Original weight} - \text{weight after washing}}{\text{Original weight}} \times 100 = \text{per cent of clay and silt."}$$

STANDARD METHOD OF TEST FOR ORGANIC IMPURITIES IN SANDS FOR CONCRETE. SERIAL DESIGNATION: C40-22

"This method is issued under the fixed designation C40; the final number indicates the year of original adoption as standard, or in the case of revision, the year of last revision. Proposed as tentative, 1921; adopted, 1922.

"**1. Scope.**—The test herein specified is an approximate test for the presence of injurious organic compounds in natural sands for cement mortar or concrete. The principal value of the test is in furnishing a warning that further tests of the sand are necessary before they be used in concrete. Sands which produce a color in the sodium hydroxide solution darker than the standard color should be subjected to strength tests in mortar or concrete before use.

"**2. Sample.**—*a.* A representative test sample of sand of about 1 lb. shall be obtained by quartering or by the use of a sampler.

Procedure.—*b.* A 12-oz. graduated glass prescription bottle shall be filled to the 4-oz. mark with the sand to be tested.

"*c.* A 3% solution of sodium hydroxide (NaOH) in water shall be added until the volume of sand and liquid after shaking gives a total volume of 7 liquid oz.

"*d.* The bottle shall be stoppered and shaken thoroughly and then allowed to stand for 24 hr.

"*e.* A standard color solution shall be prepared by adding 2.5 cc. of a 2% solution of tannic acid in 10% alcohol to 22.5 cc. of a 3% sodium hydroxide solution. This shall be placed in a 12-oz. prescription bottle, stoppered and allowed to stand for 24 hr., then 25 cc. of water added.

"**Color Value.**—*f.* The color of the clear liquid above the sand shall be compared with the standard color solution prepared as in Par. *e* or with a glass of color similar to the standard solution.

"3. Solutions darker in color than the standard color have a 'color value' higher than 250 parts per million in terms of tannic acid."

"**Color Values.**—While it is not practicable to give exact values for the reduction in strength corresponding to the different colors of solution, the tests made thus far show this relation to be about as follows:

Color number (actual color prints can be obtained from Cement Association)	Reduction in compressive strength of 1.3 mortar at 7 and 28 days, %
Fig. 1	None
Fig. 2	10– 20
Fig. 3	15– 30
Fig. 4	25– 50
Fig. 5	50–100

"Washing dirty sands has the effect of greatly reducing the quantity of organic impurities. Even after washing, however, sands should be examined in order to determine whether the organic impurities have been reduced to harmless proportions.

"The following list includes sufficient apparatus for making five field tests at a time:

"Five 12-oz. graduated prescription bottles; stock of 3% solution of sodium hydroxide (dissolve 1 oz. of sodium hydroxide in enough water to make 32 oz.).

"This test does not give satisfactory results when lignite is present in the sand. Lignite is a mineral coal of recent geological origin. It is known commonly as 'brown or sud' coal."

Water Tests.—Water must be clean and pure, free from organic impurities or oily content.

The usual tests are for:

1. Organic impurities (see p. 738).
2. Alkaline or acid reactions. This is determined by the common litmus-paper test, and if a strong acid or alkaline reaction is shown the water should be rejected.

Proposed Abrasion for fine Aggregate.—The following is suggested as a tentative method[1] for determining the resistance of the fine aggregate to abrasion.

"The fine aggregate is washed and dried at a temperature not exceeding 110°C. All material retained on the ¼" sieve and all material passing a standard 50-mesh sieve is discarded. Five hundred grams of the portion passing a ¼" screen and retained on a 50-mesh sieve are placed in a Deval abrasion cylinder with a charge of 250 g. of 9⁄16" commercial steel bearing balls (21 balls weigh practically 250 g.). The weight of the balls is to be within 1% of the required 250 g. The charge in the Deval abrasion cylinder is rotated for 2000 revolutions at the rate of 33 r.p.m. The sample of sand is removed and sieved over a 100-mesh sieve. The sample is preferably divided in three portions for sieving, the sieving being completed over a white sheet of paper, and is continued until practically no dust passes the sieve when shaken for 1 min. The portion retained on the 100-mesh sieve is weighed. Five hundred grams, minus the weight of the samples retained on the 100-mesh sieve after abrasion, is taken as the loss on abrasion. This weight divided by 5 gives the percentage of wear."

SUMMARY FINE AGGREGATE

In order to secure suitable qualities, minimum requirements determined from the above tests should be definitely specified. For asphaltic-concrete sand requirements see page 494.

The following specifications in regard to cement-concrete sand are now being used by highway departments in several of the states:

"Sand for use in Portland-cement-concrete roads shall be of the following gradation: 100% shall pass a ¼" screen, not more than 20% shall pass a 50-mesh sieve, and not more than 6% shall pass a 100-mesh sieve. Sand may be rejected for this class if it contains more than 5% of loam and silt. Mortar in the proportion of 1 part of cement to 3 parts of the sand shall develop a compressive or tensile strength of a similar mortar of the same age, composed of the same cement and standard Ottawa sand.

"Sand for use in foundations, culverts, retaining walls, etc. shall not contain more than 8% of loam and silt. Mortar in the proportion of 1 part of cement to 3 parts of the sand when tested shall develop a compressive or tensile strength of at least 80% of the strength of a similar mortar of the same age, composed of the cement and standard Ottawa sand.

"Screenings, if substituted wholly or in part for the above sand, should meet the following requirements:

"They shall be free from dust coating or other dirt. One hundred per cent shall pass a ¼" screen and not more than 6%, shall pass a No. 100 sieve. Mortar in the proportions of 3 parts of the screenings or mixed screenings

[1] Agg's "Construction of Roads and Pavements."

and sand with 1 part of cement shall develop a strength equal to a sand for which it is to be substituted.

"The best and safest way in the selection of a concrete sand is to have a fair representative sample from the deposit listed. After this is found to meet the requirements, it is necessary to have constant and careful field inspections and tests made as the deposit is worked.

"The use of screenings is not advisable on any concrete work, except where a good grade of sand is not available. When used, the product must be inspected constantly and tested, as it is likely to vary to a considerable degree. Screenings from the softer limestones should not be used, as the material is apt to "ball" in the mixer.

"Sand used for grout in brick and stone-block pavements must be fine enough to insure it getting between the joints of the block, but an excessively fine sand should be avoided, as it weakens the grout. Some states and many municipalities require the grout sand to pass a No. 20 sieve and not more than 30% pass a No. 100 sieve. Such sand should not contain more than 5% of loam and silt."

9. COARSE AGGREGATE

Coarse aggregate for use in structural concrete should be of hard, durable stone gravel or blast-furnace slag (see table of tests) free from coating of any kind. For use in concrete pavement, stone and gravel should be hard, tough, and absolutely clean. For use in culverts, retaining walls, etc., stone, gravel, or slag should be of sound, unweathered material, clean and free from coating. It should not contain more than 10% of soft stone or shale. Gravel containing a large percentage of thin, flat stone should not be used. Detail test methods follow.

For reinfored concrete the size of the stone is usually ½ to 1″ in order to facilitate the compacting of the concrete between the reinforcing bars or mesh. For plain concrete a mixed size is used, ranging from ½ to 3½″; a scientifically graded stone reduces the amount of mortar required, but the structures in road work are so small that it does not pay to attempt to reduce the voids in this manner and the size that is available is used, varying the proportions of mortar to get a dense product. For extensive concrete pavement of the first class, graded sizes are feasible.

The use of slag in concrete is still a debatable matter but if proved to be reasonable will add materially to the source of concrete materials. All the indications and service tests seem to indicate that it is suitable for paving bases, but that its use for concrete roads is to be avoided unless other suitable materials are prohibitive in cost.

STANDARD METHOD FOR MAKING A MECHANICAL ANALYSIS OF BROKEN STONE, BROKEN SLAG, OR GRAVEL PEBBLES[1]

"The method shall consist of drying at not over 110°C. (230°F.) to a constant weight a sample weighing in pounds six times the diameter in inches of the largest holes required; passing the sample through such of the following size screens having circular opening as are required or called for by the specifications, screens to be used in the order named: 8.89 cm. (3½″), 7.6 cm. (3″), 6.35 cm. (2½″), 5.08 cm. (2″), 3.81 cm. (1½″), 3.18 cm. (1¼″), 2.54 cm. (1″), 1.90 cm. (¾″), 1.27 cm. (½″), and 0.64 cm. (¼″); determining the percentage by weight retained on each screen; and recording the mechanical analysis in the following manner:

[1] American Society For Testing Materials, Standard Method, Serial Designation: D18-16, slightly modified, AGG's "Construction of Roads and Pavements."

Passing 0.64-cm. (¼″) screen	...... %
Passing 1.27-cm. (½″) and retained on a 0.64-cm. (¼″) screen	...... %
Passing 1.90-cm. (¾″) and retained on a 1.27-cm. (½″) screen	...... %
Passing 2.54-cm. (1″) and retained on a 1.90-cm. (¾″) screen	...... %
	100.00%"

Weight per Cubic Foot and Void Tests on Coarse Aggregate.—The weight per cubic foot of coarse aggregate shall be determined as follows:

A cylindrical measure of at least 14 cu. ft. capacity with inside diameter approximately equal to inside height, or a box approximately cubical in shape and of not less than ½-cu. ft. capacity, should be used.

Ordinarily, the determination should be made on aggregate in air-dry condition. When the aggregate contains an appreciable amount of moisture, the percentage of water by weight should be determined and recorded.

About ¼ of the total amount of aggregate necessary to fill the measure is first introduced in such manner as to avoid separation of sizes. This material is then shaken down by rocking the measure from side to side until no further settlement takes place. The process is repeated until the measure has been filled to overflowing, after which it is struck off level with the top with a straightedge and weighed.

The percentage of voids in the aggregate may be determined from the weight per cubic foot and specific gravity in the usual manner.

Method of Determining the Weight of Fine Aggregate per Cubic Foot.—For tests on fine aggregate use a cylindrical metal measure having inside diameter equal to inside depth. A measure of capacity of ⅕ to ½ cu. ft. is suggested, but a measure as small as 1/20-cu. ft. capacity may be used.

Ordinarily, the weight per cubic foot should be determined on air-dry material. When the aggregate contains an appreciable amount of moisture the percentage of water by weight should be determined and recorded.

Fill the measure one-third full, puddle with 25 to 30 strokes from a ½″ round steel bar 20″ long, pointed at the lower end. Continue filling and puddling in like manner until the measure is full, then strike off the top by a rolling motion with the bar. Determine the weight of the contents of the measure and calculate the weight in pounds per cubic foot.

Specific Gravity and Absorption Tests on Stone or Other Coarse Materials.—The apparent specific gravity is obtained by weighing the water displaced by a sample of the material weighing approximately 1000 g. broken into pieces about 1¼″ in diameter. A special type of vessel is used. It consists of a galvanized-iron cylinder closed at one end, and measuring 5″ in diameter by 8″ high. A brass spout ½″ in diameter is soldered into the side of the cylinder 6″ from the bottom. The spout is inclined at an angle of 2 with the horizontal and is 2½″ long. A notch is filed across its lower end, as shown, to stop the drip from the displaced water. In determining the specific gravity, the dried and cooled sample is weighed to the nearest 0.5 g. and immersed in water for 24 hr.

The pieces are then individually surface dried with a towel, the sample reweighed and immediately placed in the cylinder, which has been filled previously to overflowing with water at room temperature.

The weight of water displaced by the sample is used to calculate its apparent specific gravity. The difference between the original weight of the sample and its weight after 24 hr. is used to determine the absorption.

Abrasion Tests for Gravel.—The aggregate is screened first through screens having circular openings 2, 1½, 1, and ½″ in diameter. The sizes used for this test are divided equally between those passing the 2″ and retained on a 1½″ screen, passing a 1½″ screen and retained on a 1″ screen, passing a 1″ screen and retained on a ¾″ screen, passing a ¾″ screen and retained on a ½″ screen. The material of these sizes is washed and dried. The following weights of the dried stone are then taken: 1250 g. of the size passing the 2″ screen and retained on the 1½″ screen, 1250 g. of the size passing the 1½″ and retained on the 1″ screen, 1250 g. passing the 1″ screen and retained on the ¾″ screen, and 1250 g. passing the ¾″ screen and retained on the ½″ screen. This material is placed in the cast-iron cylinder of the Deval machine, as specified for the standard abrasion test on stone. Six cast-iron spheres 1.875″ in diameter and weighing approximately 0.95 lb. (0.45 kg.) each are placed in the cylinder as an abrasive charge. The spheres are the same as those used in the standard paving-brick rattler test.

After the cast-iron spheres have been placed in the cylinder the lid is bolted on and the cylinder mounted in the frame of the Deval machine. The duration of the test and the rate of rotation are the same as specified for the standard test for stone, namely, 10,000 revolutions at the rate of 30 to 33 r.p.m. At the completion of the test the material is taken out and screened through a 16-mesh sieve. The material retained upon the sieve is washed and dried and the per cent loss by abrasion of the material passing the 16-mesh sieve calculated.

When the materials have a specific gravity below 2.20, a total weight of 4000 g. made up of the four groups of sizes described above, instead of 5000 g., shall be used in the abrasion test.

Proposed Test for Percentage of Shale in Gravel.—It is suggested that, for the separation of shale and other light unsatisfatory pieces from concrete aggregate, a solution of zinc chloride ($ZnCl_2$) or some other satisfactory liquid having a specific gravity of approximately 1.95 be used. A sample of the pebbles should be first dried to constant weight at not over 110°C., and then placed in a container of suitable size partially filled with the solution. Agitate for 5 min., skim off the lighter materials, and then pour the solution through a sieve which will retain the pebbles. Repeat the operation until the entire sample has been separated. Dry to constant weight, measure the volume of retained material, and compute the percentage by volume of shale or other soft material.

STANDARD METHODS OF MAKING AND STORING SPECIMENS OF CONCRETE IN THE FIELD. SERIAL DESIGNATION: C31-21

"These methods are issued under the fixed designation C31; the final number indicates the year of original adoption as standard, or, in the case of revision, the year of last revision. Proposed as tentative, 1920; adopted, 1921, American Society for Testing Materials.

"1. **Scope.**—The methods herein specified apply to molding and storing of test specimens of concrete sampled from concrete being used in construction.

"2. **Size and Shape of Specimen.**—The test specimens shall be cylindrical in form with the length twice the diameter. In general, a mold whose diameter is not less than four times the diameter of the largest-size aggregate shall be used. (The sizes most commonly used are 6 by 12″ and 8 by 16″ cylinders.)

"3. **Molds.**—*a*. The molds shall be cylindrical in form, made of non-absorbent material, and shall be substantial enough to hold their form during the molding of the test specimens. They shall not vary in diameter more than 1⁄16″ in any direction, nor shall they vary in height more than 1⁄16″ from the height required. They shall be substantially water-tight so that there will be no leakage of water from the test specimen during molding.

"*b*. Each mold shall be provided with a base plate having a plane surface and made of non-absorbent material. This plate shall be large enough in diameter to support the form properly without leakage. Plate glass or planed metal are satisfactory for this purpose. A similar plate should be provided for covering the top surface of the test specimen after being molded.

"*c*. Suggestions for suitable forms are shown in accompanying figures.

"4. **Sampling of Concrete.**—*a*. Concrete for the test specimens shall be taken immediately after it has been placed in the work. All the concrete for each sample shall be taken from one place. A sufficient number of samples—each large enough to make one test specimen—shall be taken at different points so that the test specimens made from them will give a fair average of the concrete placed in that portion of the structure selected for tests. The location from which each sample is taken shall be noted clearly for future reference.

"*b*. In securing samples, the concrete shall be taken from the mass by a shovel or similar implement and placed in a large pail or other receptacle, for transporting to the point of molding. Care shall be taken to see that each test specimen represents the total mixture of the concrete at that place. Different samples shall not be mixed together but each sample shall make one specimen.

"5. **Molding the Specimens.**—*a*. The pails or other receptacles containing the samples of concrete shall be taken as quickly as possible to the place selected for molding test specimens. To offset segregation of the concrete occurring during transportation, each sample shall be dumped into a non-absorbent water-tight receptacle and, after slight stirring, immediately placed in the mold.

"*b*. The test specimens shall be molded by placing the concrete in the form in layers approximately 4″ in thickness. Each layer shall be puddled with 25 to 30 strokes with a 5⁄8 to 3⁄4″ bar about 2′ long, tapered slightly at the lower end. After puddling the top layer, the surface concrete shall be struck off with a trowel and covered with the top cover plate, which will later be used in capping the test specimens."

"6. **Capping Specimens.**—Two to four hours after molding, the test specimens shall be capped with a thin layer of stiff neat cement paste in order that the cylinder may present a smooth end for testing. The cap can best be formed by means of a piece of plate glass 1⁄4″ thick and of a diameter 2 or 3″ larger than that of the mold. This plate is worked on the fresh cement paste until it rests on top of the form. The cement for capping should be mixed to a stiff paste some time before it is to be used in order to avoid the tendency of the cap to shrink. Adhesion of the concrete to the top and bottom plates can be avoided by oiling the plates or by inserting a sheet of paraffined tissue paper.

"7. **Removal of Specimens from Forms.**—At the end of 48 hr. the test specimens shall be removed from the molds and buried in damp sand except in case the molds shown in Fig. 3 are used; in this case test specimens may be buried in damp sand without removal of the mold, thus permitting shipping of the test specimens in the molds.

"8. **Storage of Specimens.**—*a*. The test specimens shall remain buried in damp sand until 10 days prior to date of test. They shall then be well

packed in damp sand or wet shavings and shipped to the testing laboratory, where they shall be stored either in a moist room or in damp sand until the date of test.

"*b*. Should a 7-day test be required, the test specimens shall remain at the works as long as possible to harden and then shall be shipped so as to arrive at the laboratory in time to make the test on the required date."

TENTATIVE METHOD OF TEST FOR CONSISTENCY OF PORTLAND-CEMENT CONCRETE. SERIAL DESIGNATION: D138-25T

"This is a *Tentative Standard* only, published for the purpose of eliciting criticism and suggestions. It is not a Standard of the Society and until its adoption as Standard it is subject to revision. Issued, 1922, American Society for Testing Materials.

"**1. Scope.**—This test covers the method to be used both in the laboratory and in the field for determining consistency of concrete[1] to be used for concrete pavements or for concrete base for pavements.

"**2. Apparatus.**—The test specimen shall be formed in a mold of No. 16 gage galvanized metal in the form of the lateral surface of the frustrum of a cone with the base 8″ in diameter, the upper surface 4″ in diameter, and the altitude 12″. The base and the top shall be open and parallel to each other and at right angles to the axis of the cone. The mold shall be provided with foot pieces and handles as shown in accompanying figure.

"**3. Sample.**—When the test is made at the mixer, the sample shall be taken from the pile of concrete immediately after the entire batch has been discharged. When testing concrete that has been hauled from a central mixing plant, the sample shall be taken from the concrete immediately after it has been dumped on the subgrade.

"**4. Procedure.**—The mold shall be placed on a flat, non-absorbent surface, such as a smooth plank or a slab of concrete, and the operator shall hold the form firmly in place, while it is being filled, by standing on the foot pieces. The mold shall be filled to about one-fourth of its height with the concrete, which shall then be puddled, using 20 to 30 strokes of a ½″ rod pointed at the lower end. The filling shall be completed in successive layers similar to the first and the top struck off so that the mold is exactly filled. The mold shall then be removed by being raised vertically, *immediately* after being filled. The molded concrete shall then be allowed to subside until quiescent and the height of the specimen measured.

"**5. Slump.**—The consistency shall be recorded in terms of inches of subsidence of the specimen during the test, which shall be known as the slump.

Slump = 12 − inches of height after subsidence."

Test for Clay in Sand Clay, Topsoil, and Semigravel.—Dry 500 g. of the material at a temperature below 350°F. (176.6°C.) to a constant weight. Gently pulverize to break down soft clods or masses, but not to grind or break hard material. Pass through a 10-mesh sieve, weigh the coarse residue, and record as "coarse material." Use the material passing through the 10-mesh sieve as the starting point of a percentage analysis as follows:

Weigh out two samples of 50 g. of this material for duplicate analysis. Place each in a tared wide-mouth bottle (5- to 6-cm. diameter and about 12 to 15 cm. high). Add about 5 cc. of dilute ammonia water and about 200 cc. of water. Close with a cork or glass stopper and shake thoroughly for 20 min. Allow the sample to settle 8 min. and decant carefully or siphon off the supernatant liquid to a depth of 8 cm. below the surface of the liquid. (The depth of the liquid in the bottle should be sufficient to leave about 4 cm. below the point of siphoning.) Fill the bottle again with water, shake for 3 min., allow settlement, and siphon off as before.

[1] This test is not considered applicable when there is a considerable amount of coarse aggregate over 2″ in size in the concrete. The committee is now working on a method suitable for determining the consistency of concrete using aggregate over 2″ in size.

Repeat the process until the supernatant liquid is clear. Be careful to wash the stopper and neck of the bottle free from coarse material before decanting.

Dry bottle and washed material to constant weight at between 100°C. (212°F.) and 110°C. (230°F.), weigh and determine net weight of washed material.

$$\frac{\text{Original weight} - \text{washed weight}}{\text{Original weight}} \times 100 = \text{per cent clay and silt.}$$

As a check the washings drawn off shall be collected and evaporated to dryness for direct recovery of the fine sediment classed as clay and silt.

$$\frac{\text{Weight of residue}}{\text{Original weight}} \times 100 = \text{per cent clay.}$$

The determinations on the two samples shall check within 1% to be acceptable.

Tests for Semigravel, Topsoil and Sand Clay.—Wash the contents of the bottle cleanly into a porcelain evaporating dish and carry to dryness on a water bath. The dried residue should be carefully scraped from the dish and passed through a nest of 20-, 60-, 100-, and 200-mesh sieves. The residue retained on each sieve is weighed and recorded as sand of the respective sizes. Their sum constitutes the total "sand." The residue passing the 200-mesh sieve and caught in the pan is weighed and recorded as "silt." Duplicate samples should check within 1%.

a. The coarse material should be examined for hardness and with the magnifying glass to identify its character as quartz, hard-iron compounds, feldspar, schistose material, or indurated clay. Hard quartz or iron gravels are valuable in themselves and as indicating the quality of the finer aggregate. Feldspar, mica, and clay nodules are worthless and indicate that the accompanying soil is poor for road building.

b. The sands should be examined with the magnifying glass for identification as quartz and for the presence of mica scales or feldspar needles. If mica or feldspar is present in appreciable amounts the sample should be rejected.

c. When the clay is recovered by evaporation, it can be examined for tenacity by cementing together two glass plates, each 1" wide, set at right angles, with a layer of clay whose thickness is fixed by a fine bent wire laid between the plates. The moist clay covers the wire on one plate, and the other plate is squeezed down tightly on the wire. After drying, the one plate held firmly against cleats, wire slings are run symmetrically from the ends of the upper plate to one arm of a beam balance, and the tension necessary to separate the plates is given by shot or weights in the other pan of the balance. This test is tedious and is of service chiefly on low-grade samples which are of doubtful efficiency, but which represent the only available material for local construction.

d. Approximate test for tenacity of mixture can be made as follows:

Make cylinders from the material passing the 10-mesh sieve, 25 mm. The material is worked into a stiff mud and molded under 132 kg. per square centimeter pressure. Dry thoroughly at 100°C. (212°F.) and break by the small Page impact machine for testing

cementing value, using a 1-kg. hammer and 1-cm. drop. Record the number of strokes as the relative measure of tenacity.

Usually the plastic character and adhesiveness of a good road soil can be judged by the feeling of the mud made from this material, its adherence to the hands, and its strength under light pulling.

PART II

DETAIL DATA FOR SURVEYS-DESIGN AND CONSTRUCTION

Introduction.—Part II takes up a discussion of detail methods of survey, design, estimating, and construction. The essential general attitude in regard to detail methods which must be continually borne in mind and impressed on the engineering force can be briefly summarized as follows:

The survey work must be *accurate and complete*, as it provides the fundamental information for the design and the accurate estimate and measurement of quantities. Satisfactory survey work will range in cost from \$100 to \$400[1] per mile and any effort to cut cost below that required for excellent work is very short-sighted policy. Careless work is often done in order to cut the apparent cost of engineering, but it generally adds to the final total cost and is unsatisfactory to both engineers and contractors.

Effective design is based on the principle of the preparation of *alternate comparative designs* in order to pick the most suitable or economical solution. By the use of this method of alternate designs a good engineer will reduce construction costs at least 10 to 20-% below that obtained by the usual stereotyped application of standards with little thought to the local problem. First-class office design costs from \$150 to \$400 per mile and any effort to cut this cost below the amount required for thorough design is poor economy, as the authors know from an experience of over 20 years. Small bridge surveys and design will cost from ⅔ to 2% of the cost of the structure for careful and economical design.

Estimates of quantities should be liberal in order to avoid the necessity of supplementary agreements during the progress of construction, but in order not to mislead the contractor in making his bid it is necessary for the estimates to show the probable minimum amount for each item, with a statement of the amount allowed for contingencies (see pp. 1011 and 1088). *Cost estimates should be fairly liberal.* They should never be below an amount which will insure reasonable profit with ordinary favorable luck. This matter of cost is very important, as a poor contract price is almost certain to result in inferior work, even with good inspection control.

The essential of construction inspection is insistence on *good quality of work without needless interference with the contractor's choice of methods.* Construction practice is the most essential part of successful highway programs and is generally the poorest managed part of the engineering program. This is largely due to

[1] Average cost of surveys and plans for Kentucky state roads in 1923 was \$287 per mile.

the policy of low pay for field engineers and inspectors. Under this general policy it is impossible to get high-grade men who will give the work their entire undivided attention. Low-grade men are no match for high-grade contractors or even well-paid foremen, and the results are often not very creditable to the inspection force. Effective supervision of construction costs from $600 to $1000 per mile and any effort to cut cost on the score of engineering pay-roll economy is political bunkum and very poor economic policy.

Lack of thoroughness and care is a common trait which often shows in extreme form in public works programs. It is most certainly desirable to combat this tendency, which is very well illustrated by the anecdote of the American tourist in Spain, who on hearing that it had taken 500 years to build a famous cathedral remarked, "Well in God's country where I come from we could build one of those things and have it fall down on us all inside of 5 years."

CHAPTER XII

PRELIMINARY INVESTIGATIONS

Introduction.—The object of all preliminary investigations for any type of engineering improvement is to secure basic data on which a reasonable program or detailed design can be worked out. *Preliminary investigations are the most important part of the engineering program, as they set the broad general plan.* They should be thoroughly done by the most experienced engineers available, whose judgment has been developed by extended experience with the general conditions to be met. Too often this part of the engineering program is carelessly done due to hesitation in spending money before a project is assumed, but this policy is very short sighted, as it often results in excessive expenditure for detailed surveys of alternate routes and for irrational pavement and bridge designs.

Cost of Preliminary Investigations.—The cost of first-class investigations of this kind ranges from \$5 to \$80 per mile, depending on the country to be traversed. A cost of \$5 to \$15 per mile is a fair average for long mountain road projects similar in character to the road work done by the U. S. Office of Public Roads in the West, and a cost of \$10 to \$20 per mile for high-type road reports in the eastern states. Reconnaissance location surveys in heavily timbered pioneer territory may cost as high as \$50 to \$70 per mile.

The field work and reports deal with the following main features:

1. Probable traffic.
2. General location.
3. Construction materials.
4. Special problems.
5. Cost estimate of alternate types.
6. Report.

HIGH-TYPE ROAD INVESTIGATIONS IN WELL-SETTLED DISTRICTS

The improvement generally consists of betterments to an existing road, the location of which is in most cases fixed by existing rights of way except for short relocations. The choice of which road to improve is made by local boards or the State Highway Commissioner so that when the problem reaches the field engineer his work is usually confined to a definite report on a definite road, although in some cases where there is a dispute as to the relative merits of alternate routes it is necessary to investigate two or more possible routes.

1. **Probable Traffic.**—The probable present and future traffic governs reasonable recommendations as to alignment, grade and type and width of pavement. For principles and methods of estimating traffic, present and future see pages 28 to 33; for reasonable type and width of payment, pages 6 to 9; for reasonable alignment, pages 113 to 121; for maximum grades, pages 74 to 113; for roadway section, pages 122 to 179; and for maximum allowable expenditure, pages 1 to 16.

2. **General Location.**—The principles of relocation are detailed in pages 74 to 83.

3. **Construction Materials** (*Field Work*).—The investigation for local material is very important. Careless work in this particular results in specifying impracticable or needlessly expensive sources of supply for materials and often in the selection of an unreasonable type of construction. A careless estimate of the quantity of available local material also causes trouble during construction by a shortage in supply.

It is important not only to determine the amount of local material but also its character, as, for example, a local gravel may be suitable for a first-class bottom for macadam construction but not suitable for a concrete pavement, or it may be suitable for a concrete paving base but not for a concrete road taking the traffic directly. A local hard sandstone may be suitable when bound with bitumen and would not act well if water bound with its own screenings, etc. The necessary properties of stones, gravels, sands, etc., are given in the chapter on Materials, and in Specifications.

Any preliminary report should cover the sources of supply and approximate cost at pit or switch of the following materials:

Gravels, suitable for:

Bottom courses
Top courses
Structural concrete
First-class concrete pavement
Concrete paving base
Subbase filler.

Stone, slag, etc., suitable for:

Subbase
Bottom course
Water-bound macadam top
Bituminous macadam pavement
First-class concrete pavement
Concrete paving base
Structural concrete.

Sand suitable for:

Bottom-course filler
Cushion sand
Structural concrete sand
First-class concrete paving sand
Fine and coarse sand for sheet asphalt.

Miscellaneous:

Bitumens
Tars
Paving brick
Stone block
Asphalt block
Wood block
Stone or brick cubes.

Water supply, location and quality.

A convenient method of recording the location of materials is s follows:

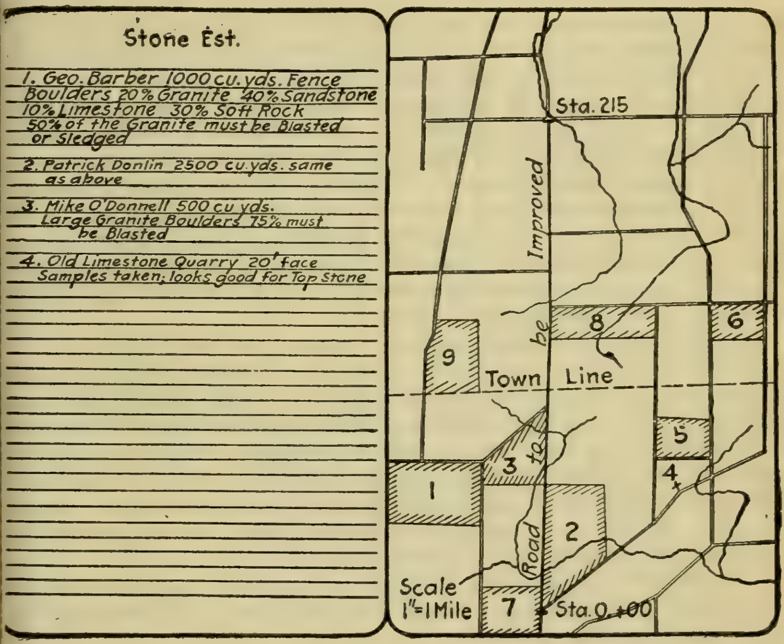


FIG. 258.

Unloading Points for Freight.—Provided U. S. geological maps re obtainable, the position of sidings may be marked on the sheets. 'he notes for each siding show its car capacity, whether or not an levator plant can be erected, and, if hand unloading is necessary, 'hether teams can approach from one side or two. They should lso show any coal trestle that can be utilized in unloading and the ocation and probable cost of any new sidings that will materially educe the length of the haul. Canal or river unloading points re shown in the same manner.

Sand, Gravel, and Filler Material.—The position of sand and gravel its and filler material are noted with their cost at the pit; if no

local material is available, the cost, f.o.b. at the nearest siding, i given. Samples are taken and tests made.

Stone Supply.—Provided imported stone is to be used, the wor is simplified to determining the rate, f.o.b., to the various siding for the product of the nearest commercial stone-crushing plant tha produces a proper grade of stone.

In case local stone is available, the location of quarries or outcrop is shown, the amount of stripping, if any, and the cost of quarr rights. If the estimate will depend upon rock owned by a singl person, an option is obtained to prevent an exorbitant raise in price

In case of field or fence stone, a careful estimate is made of th number of yards of boulder stone available, the owners' name: what they will charge for it, the position of the fences or pile relative to the road, or side roads, and, if the fences are not abut ting on a road or lane, the length of haul through fields to the neares road or lane. As fences are usually a mixture of different kind of rock, the engineer estimates the percentage of granite, limestone sandstone, etc., and the percentage that will have to be blasted c sledged in order to be crushed by an ordinary portable crushe: The amount of field stone required per cubic yard of macadam i given in estimates (p. 1172). If there is a large excess of stone, careful estimate need not be made, only enough data being co lected to determine the probable position of the crusher set-up and the average haul to each set-up. If a sufficient supply i doubtful, a close estimate is made as outlined above, and option obtained from the various owners.

Samples of the different rocks are tested (see Materials).

Simple field tests can be made, but if the department has a testin laboratory it is better to take samples and have a careful test mad and recorded. As these tests are made, the location of the sampl and result of the tests are recorded on a large map of the distric which in the course of a few years shows at a glance the differen sources of supply of acceptable materials for the entire count or state and saves future duplication of work for reconstructior maintenance, and adjacent improvements.

The method of sampling and the amounts of material require for a good test are quoted below from the New York State Instruc tions for Sampling Materials.

"**Sampling.**—Amounts of material required for laboratory tests are a follows:

"Samples of material will be taken by a duly authorized employee of th department, in its place of occurrence or manufacture or delivery by carrie: These samples must be taken from different parts of the lot of material to b tested, so as to be fairly representative, and must be unmixed with foreig substances and placed in clean and safe receptacles; and they must confor in all respects to the requirements given under the special headings. The must be carefully and securely packed, enclosing notification slip properl protected from wear and injury, and sent express "collect" to the Bureau c Tests, State Highway Commission, Albany, N. Y., a postal card notice bein mailed at the same time. Envelopes, scoops, cans, thermometers, etc. fc use in taking the samples may be had from the Bureau of Finance and Audi at Albany.

"In the case of materials sampled at the place of manufacture, chec samples may be required; these are to be taken and treated the same a ordinary samples, except that the packages must be marked Check Sample:

and the use of the material need not be prohibited pending the results of the check tests.

"*Sand and Gravel.*—The character of the supply, whether from stream bed, bank, crusher bins, etc., is to be stated; also the use for which it is intended, whether for concrete foundations or other structures, binder for water-bound macadam, filler or wearing carpet or blotter for bituminous macadam, or for aggregate in water-bound or bituminous macadam, etc.

"Material which will all pass through a ¼″ screen will be considered sand. Each sample of sand or screenings shall be ¾ cu. ft. in volume; of gravel, 1½ cu. ft.

"A small sample shall be taken from each test sample sent, and be kept on the contract as a measure of the quality of material.

"Each sample is to be shipped in a tight box or in a clean, closely woven bag from which there will be no leakage; the usual identification slip is to be enclosed. In numbering samples, sand and gravel are to be treated as one material, not as two.

"Notification of acceptance or rejection may be expected to arrive at the division office 20 days after the submission of the samples and data, provided the need of a retest does not cause delay.

"*Cement.*—One sample is to be taken from at least every 10 bbl. or every 40 bags, care being taken properly to distribute the sampling over the lot. Each sample shall be not less than 27 cu. in. in volume, or enough to fill a 3″ cube. Whenever possible, samples should be forwarded in envelopes furnished by the Commission for that purpose, the envelopes being filled to the line marked thereon.

"The individual samples are not to be numbered, but each group or lot of these samples representing a single boatload or carload is to be given a lot number, and these lot numbers are to run consecutively. Not more than one boatload or carload is to be represented by one lot number.

"Receipt of notification of acceptance or rejection of cement sampled at destination may be expected to arrive at the division engineer's office 12 days after the submission of the samples and data. If cement is held for 28-day tests the division engineer will be notified accordingly.

"*Concrete.*—The concrete on each highway must be sampled for testing, the samples being taken at random from the batches used and being molded at the place and time of mixing. The work need not be delayed pending the results of the tests.

"Each sample shall be a pair of cubes measuring 6″ on the edge, or of cylinders 8″ in diameter and 16″ long; the sample is to be made in such manner as fairly to represent the concrete going into the structure. At least one sample is to be taken, and as many more as seem to be required by changes in the character of any ingredient or by any other consideration.

"In concrete pavement work (whether foundation or top course) one pair of cubes or cylinders should be sent for every 500 cu. yd. Not less than two pairs are to be sent, however small the pavement.

"The sample must remain in the mold 2 days, then be buried in clean sand to age under the same conditions as the material in the structure. On the twenty-first day the samples shall be taken out and shipped.

"Each sample is to have its number painted on each piece, and is to be shipped in a box, properly protected from breakage and surface chipping, accompanied by the usual included identification and the postal notification. Especially must the class of concrete, the purpose for which it is used (kind of structure and portion), and the date and time of day when sample was mixed be stated.

"*Bituminous Material.*—When material is shipped in barrels, one sample is to be taken for every 20 or 25 bbl., the sampling being properly distributed over the lot.

"When material is shipped in tank cars one sample is to be taken from every 2000 or 2500 gal., the samples being taken from equally distributed levels in the car.

"When material bitumen is shipped in loose bulk, one sample is to be taken for every 5 or 6 tons, the samples being taken from different levels and different locations in the lot and never from the surface of the material.

"Each sample shall be not less than 14 cu. in. in volume, which volume is slightly less than ½ pt. or about the size of a 1-lb. paint can.

"It should be remembered that the bituminous material will flow at summer temperature or thereabouts, and consequently great care should be used in sealing cans and doing up packages. Whenever possible, samples should be forwarded in cans furnished by the Commission for that purpose.

"The individual samples are not to be numbered, but each group or lot representing a single boatload or carload is to be given a lot number, and these lot numbers are to run consecutively; not more than one boatload or carload of material is to be represented by one lot number.

"In order to check the weighing and marking of bituminous materia shipped in barrels, one unopened barrel out of every carload of approximately 65 bbl., or a proportionate number of barrels for each boatload, is to be selected at random and weighed. The gross weight found, and the gros weight marked on the barrel, are to be entered on the Monthly Bituminou Material Reports or the information may be recorded elsewhere and submitted to the Bureau of Tests. Any noticeable difference between th gallonage marked on a barrel and the gallonage found therein must b reported to the Headquarters office at Albany.

"The unit of measure for bituminous material is the gallon measured a the temperature of 60°F. If the volume of material is measured when hot allowance should be made for expansion according to the following table which will apply approximately to all of the different classes of bituminou material at present used on the state highways:

"Increase in volume of various classes of bituminous material whe heated from 60°F.

To 400°F. is approximately	12 %
To 350°F. is approximately	10 %
To 300°F. is approximately	8 %
To 250°F. is approximately	6 %
To 200°F. is approximately	4 %
To 150°F. is approximately	2 %

"*Stone.*—Rotten or partially disintegrated stone, or weathered specimen from the surface of a quarry or ledge, are not to be submitted.

"Samples of quarry or ledge stone must be representative of the sounc fresh, interior stone of the ledge or quarry. Such samples may be secure either by blasting or by breaking up with the sledge. If all material is c the same variety, texture, etc., one sample will suffice. If, however, ther are different varieties, separate samples are to be taken of each and repor made as to the extent, giving details as to location and position for use.

"All field stone, whether in walls, piles, or scattered over the grounc which might be used must be examined and a representative sample taken When two or more varieties of great difference in quality or texture ar observed to exist, separate samples are to be taken of each, and report mac as to the percentage of each kind, the amount of small stone which might ru through the crusher without action, and the percentage of disintegrated c badly weathered rock present.

"In taking samples from the output of crushers, 15 lb. of crushed materi not smaller than 1½" in size shall be taken, and also one piece at lea 3 by 4 by 5" shall be procured from the source of supply.

"Each sample shall weigh not less than 25 nor more than 35 lb. If th entire sample submitted is a single piece of stone, it should be remembere that a piece about the size of a man's head will weigh 25 or 30 lb. While nc less than 25 lb. are absolutely necessary in each sample, care should be take to see that the samples do not weigh over 35 lb. One piece of each samp shall be at least 3 by 4 by 5".

"Each sample is to be given a number running consecutively in eac division. This number must contain both the division number and th sample number; thus, sample 42 from division 1 would be marked 1–4. Paint or Higgins' drawing ink may be used to mark directly on the sampl or a label or tag may be securely fastened thereto.

"Samples may be shipped in boxes, burlap, grain bags, cement bag etc. It is preferred that stone be shipped in a strong bag or in a double ba which may be formed by placing one bag inside of another. If shippin in a single bag which the sample only partially fills, the bag should be securel tied just above the sample and the remaining unfilled part of the bag folde back so as completely to envelop the stone and the portion of the ba containing it; this folded-back part should then be securely tied on the othe side of the sample; this makes a tying of the bag on two sides of the stone an permits two thicknesses of the bag to surround the stone completely, and securely tied is as satisfactory as a double bag.

"Receipt of notification of acceptance or rejection of stone may be expecte to arrive at the division engineer's office 12 days after the submission of th samples and data, provided acceptance or rejection is not deferred awaitin a retest.

"The location of source of supply is to be expressed by an index number ccording to the system used in the government office at Washington, which s, that each quadrangle of the U. S. Geological Survey sheet is divided into ine sections numbered from 1 to 9, inclusive, as shown in the following plan:

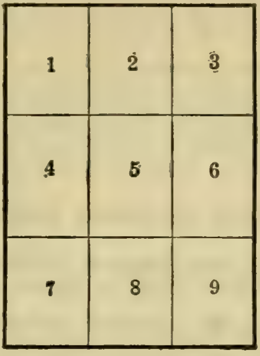


FIG. 259.

1	2	3
4	5	6
7	8	9

"The north and south sides of each section are then divided into 22 spaces esignated from A to V and the east and west sides into 32, so that the cation of the stone may be closely defined, as, for example, Quadrangle lbany, Section 7, Letter J, Number 13, which when abbreviated would ad 'Albany-7-J-13.'

"*Paving Brick.*—A sufficient number of samples in every case is to be ken to insure the use of brick of proper quality, but it should also be borne mind that the charges for transportation and testing of brick are high, and nly the smallest number of samples necessary for the purpose should be ubmitted. At least one sample is to be taken from every 200,000 brick or ss. Each sample shall consist of 30 bricks.

"If in a shipment or several shipments of the same make and kind of brick ere appear to be different classes of brick—such as brick of different degrees f burning, for example—a full sample of each class is to be taken.

"Each brick selected for the sample is to be free from cracks or other efects which would prevent its passing inspection at the road, for the mple must represent bricks which will not be culled out. Especially is it rbidden that any person financially interested in the manufacture or use of rick be present when samples are taken.

"Each sample (consisting of 30 bricks) shall receive a number, the numers to run consecutively for each road.

"The sample shall be shipped in wooden boxes, not more than 10 or 12 ricks being put in one box on account of weight and strength of package.

"Notification of acceptance or rejection of brick sampled at destination ay be expected to arrive at the division engineer's office 9 days after the ubmission of samples and data, providing the need of a retest does not use delay.

"*Asphalt Block.*—A sufficient number of samples in every case is to be ken to insure the use of block of proper quality, but it should also be borne mind that transportation and testing costs are high, and only the smallest umber of samples necessary should be submitted. At least one sample is be taken from every 100,000 blocks or less. Each sample shall const of two blocks.

"If in a shipment or several shipments of the same make and kind of block ere appear to be different classes of block, a full sample of each class is to taken.

"Each block selected for the sample is to be free from every defect that ould prevent its passing inspection at the road, for the sample must reprent blocks which will not be culled out.

"Each sample (consisting of two blocks) shall receive a number, the numbers to run consecutively for each road.

"The sample shall be shipped in a wooden box, with usual identification card and postal notice.

"Notification of acceptance or rejection of block sampled at destination may be expected to reach the division engineer's office 14 days after submission of samples and data, provide the need of a retest does not cause delay.

"*Field Sampling Steel Reinforcement.*—Two bars 18″ long for each 10 tons used. Two longitudinal and two transverse wires 18″ long for each 10 tons mesh used. Structural steel (plant inspection tests).

"**Acceptance.**—Upon completion of the testing of any set of samples the division engineer is notified of the acceptance or rejection of the material, and transmits the statement to the engineer in charge of the contract."

SAMPLE MATERIAL REPORT

MEMORANDUM LOCAL MATERIALS SURVEY FOR THE RUSH MENDON PART 1, ROAD 1392

Made by W. G. Harger, December, 1920 and January, 1921

"Previous investigations covered the availability of local materials for concrete pavement. This survey considers the availability of local material for possible macadam construction.

"In 1916, F. C. Koerner made a field estimate of local fence stone an gravel. The result of the new survey (W. G. Harger, 1920) indicates tha Mr. Koerner's estimate as to available materials was very thorough, and tha his quantities were conservative estimates.

"The main features of the situation are as follows: There is sufficier fence stone and gravel in the territory to construct a local stone macada road. The farmers, with the exception of Mr. Corcoran No. 8, and part No. 25, are all willing to give their walls and piles for use on this road, *provid the bottoms are cleaned up thoroughly.* The stone runs about 60% granite Medina sandstone bouiders, fit for top course, and 40% fit for subbase bo tom. All stone is fit for subbase bottom, but about 30% of it is too lar for economic use in a boulder bottom. About 70% of the stone as a who can be economically used for subbase bottom with a moderate amount sledging. The other 30% can most economically be used as crushed t course.

"Considering all the factors, it is probable, if macadam is used for th road, that the most suitable type would be a subbase boulder bottom, fill with coarse gravel, or waste crushed stone of sizes unsuitable for top, and top course for part of the distance of local selected crushed stone suppl mented on the east end by imported limestone.

"Filler gravel can be obtained from three pits close to the road (see ma The price for such gravel set by the owners is 25 cts. per cubic yard.

"Unloading points for imported materials are available at Rochest Junction (triple track main line, six-car capacity), and at Rush (publ switch, fifteen-car capacity).

"Water supply: Honeoye Creek the year round, and small creek near St 48 for part of year. The following map and table of quantities indicate t result of the 1920 investigation.

Submitted,
W. G. Harger.
Jan. 4, 1921."

4. Special Problems.—These include grade crossings, speci drainage, bridges, etc., the principles of which are discussed on t following pages:

Grade crossings (pp. 599 to 675).
Drainage (pp. 180 to 341).
Bridges (pp. 180 to 341).

5. Approximate Quantity and Cost Estimates.—The length the road can be obtained from maps (U. S. Geological Survey a convenient) or by autometer distances or pacing. Maps a

Harger location on map No.	Property owner	Estimated quantity, cubic yards	Per cent stone	Remarks
1	Ward	220	70% G. 30% S.	Hard to get at
2	Mead	300	60% G. 40% S.	Moderately easy
3	N. W. Mead	600	60% G. 40% S.	Easy to get (not much sledging)
4	....	550	70% G. 30% S.	Moderately easy
5	Fred Stevens	240	60% G. 40% S.	Moderately easy
6	Ad Meyers	600	60% G. 40% S.	Moderately easy
7	O'Brien	1,500	....	Moderately easy
8	Corcoran	225 + 200	....	Will not sell
9	Graves	140	....	Easy to get
10	Desmond	70	....	Easy to get (gravel pit)
11	Desmond	200	....	Easy to get
12	Conor	400	....	Moderately easy
13	Ward	150	....	Moderately easy
14	Collins	100	....	Easy
15	Szatkowski	500	....	Moderately easy
16	Moran	200	....	Moderately easy
17	Banks	200	....	Moderately easy
18	Fetzer	200	....	Easy
19	....	300	....	Moderately easy
20	Kretzer	800	....	Easy
21	Houck	70	....	Moderately easy
22	....	60	....	Moderately easy
23	Maher Bros.	400	....	Long haul
24	....	50	....	Hard to get
25	Treat	200	....	Easy
26	Myers	270	....	Easy
27	Spatahker	600	....	Moderately easy
28	Yorks	250	....	Easy
29	Lord	Gravel pit (filler)	....	Unlimited easy
30	Galvin	70	....	Easy
31	Corcoran ½ Galvin ½	(150) + 150	....	Moderately easy
32	Krenzer and Desmond	600	....	Moderately easy
33	Krenzer and Chase	40	....	Moderately easy
34	....	250	....	Moderately easy
35	....	100	....	Moderately easy
	Total..................	10,000		

generally available and serve as a convenient basis for notations A field inspection by one man, preferably on foot, furnishes th necessary data on required drainage, foundation soils, approximat amount of excavation, condition of existing bridges, and all specia features.

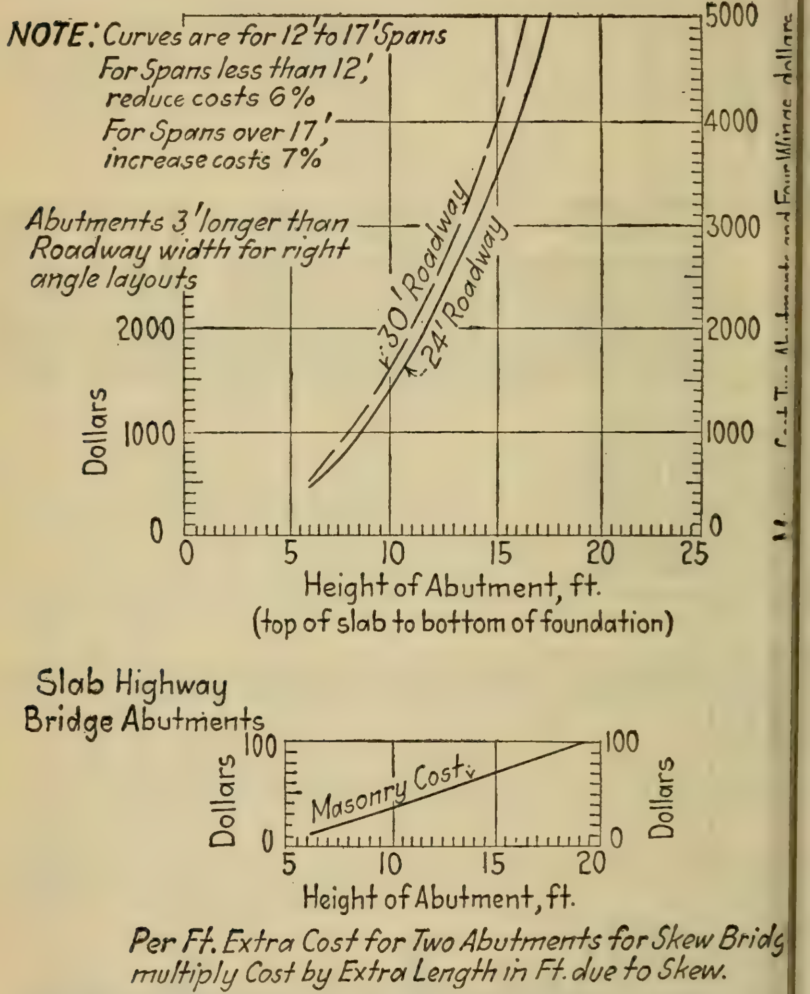


FIG. 260.—Approx. cost curves. Abutment masonry for slab ty bridges. Spans 6′ to 25′ (unit price of concrete $18 per c.y.).

Minor drainage features can generally be lumped and assum to run about $1500 per mile. (For more detailed cost, estimate ea culvert separately. See chapter on Drainage.) Special bridg must be figured in detail. (See chapter on Drainage for Standa Design, and quick-estimating diagrams. For culvert costs s

pp. 669 to 675, for bridge costs, pp. 648 to 669. For the convenience of the field man cost and quantity of the most common cases are reported in this chapter (pp. 758 to 769).

The amount of excavation per mile for ordinary rolling topography is entirely a matter of judgment, which can only be developed by personal experience in similar work. For special long hills requiring a cut and fill reduction a rough profile can be run with an Abney level, and the quantities approximated from the attached diagram. However, the item of excavation on macadam roads in ordinary topography rarely exceeds 20% of total cost, and considerable error in estimating the yardage will not greatly effect the value of the estimate.

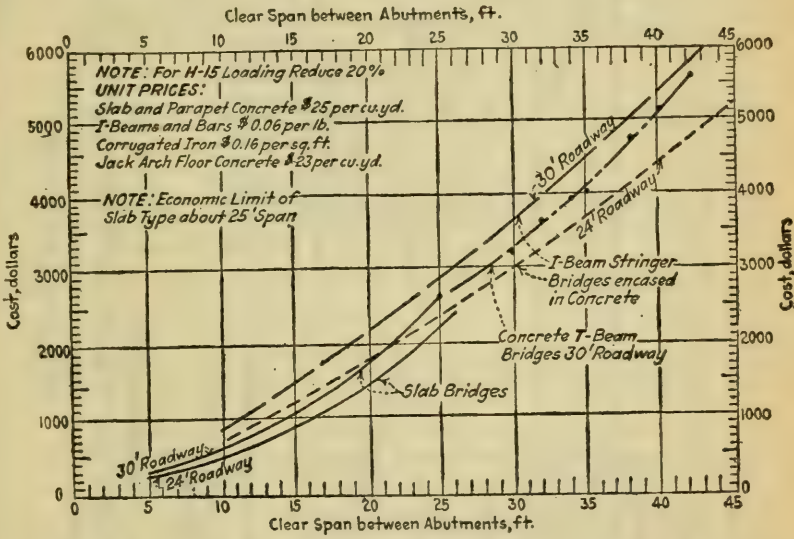
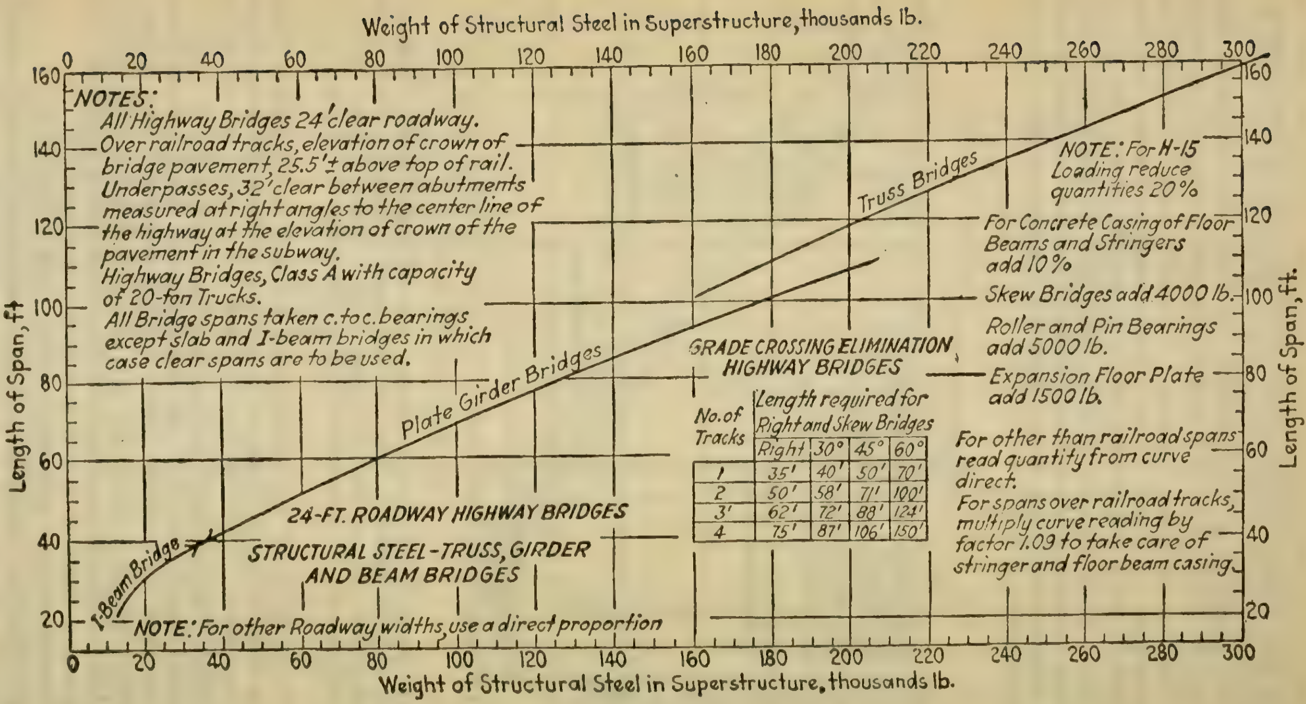


FIG. 260.—Typical cost curves. Small span bridge superstructures. H-20 loading. Based on standard bridges in the following illustrations. Slabs, Fig. 69, page 237. Steel I beam stringers. Fig. 76, page 275. Concrete T beam stringers, Fig. 73, page 252.

The character of the natural road soil has an important bearing on the depths of macadam or the use of subbase and must be carefully recorded. This can best be done by giving the character of the soil, noting whether the improved road will probably be in cut or fill at the points recorded, and specifying the recommended depths of macadam or subbase under rigid pavements. The depths of macadam for different classes of traffic and different soils were indicated in Chap. VI (p. 391), for rigid pavements on page 426. Sample notes on foundation soils are shown on page 838.

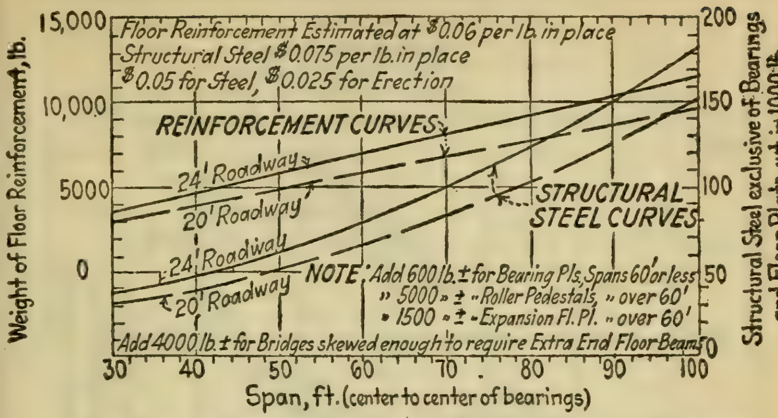
Methods of computing costs are given in Chap. XV.

The following tabulations of unit costs show the wide range in different locations and under different specifications. Reasonable unit prices for the district in question should be worked out for general reference purposes.

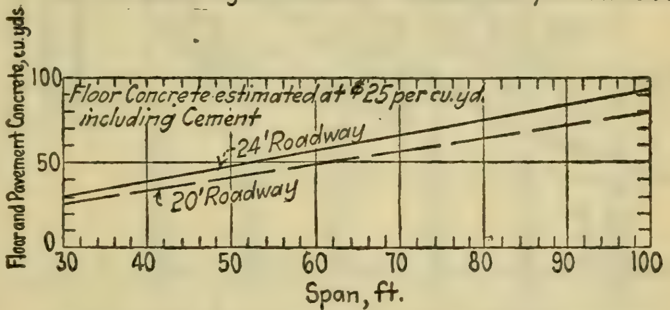


No. of Tracks	Length required for Right and Skew Bridges			
	Right	30°	45°	60°
1	35'	40'	50'	70'
2	50'	58'	71'	100'
3'	62'	72'	88'	124'
4	75'	87'	106'	150'

FIG. 261.



NOTE: Overall length of Girders 2 ft. ± more than Span as tabulated



NOTE: Depth of Floor System Center Line Top of Pavement to Bottom of Girder 36" to 42" - Approximate Quantities

FIG. 262.—Approximate quantities typical plate girders. H-20 loading. Structural steel includes girders, floor beams and stringers.

NOTE.—For skew bridge wings quantities remain constant, abutments are lengthened.

$$\text{Length} = \frac{\text{Right angle length}}{\text{Cos. skew angle}}$$

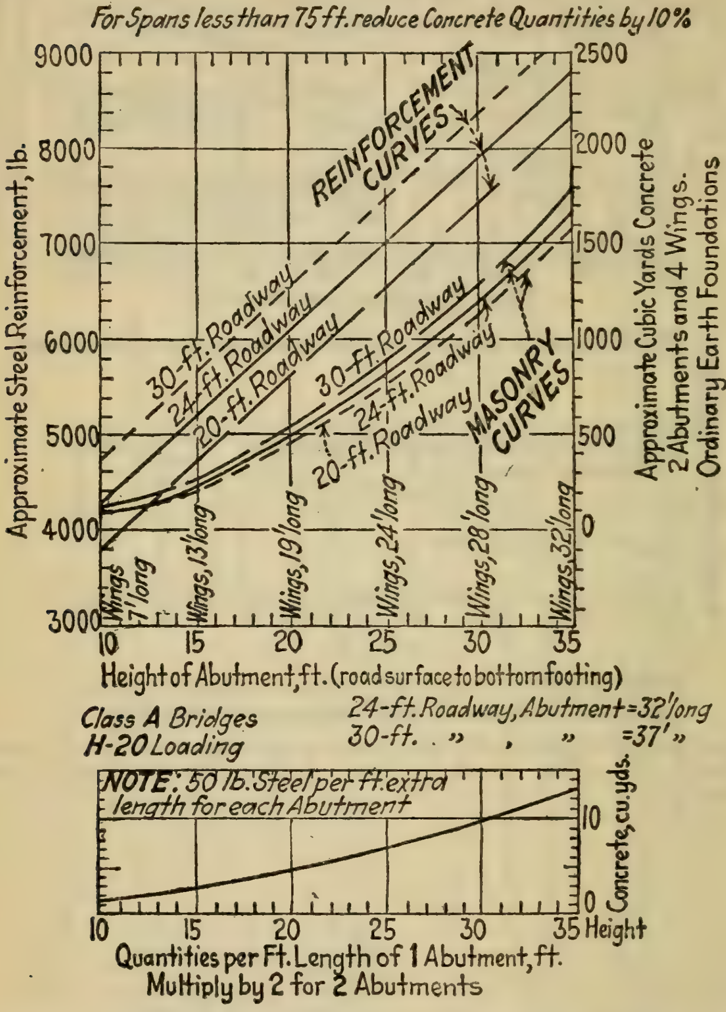


FIG. 263.—Approximate quantities of abutment masonry plate girder. Type of bridge. 40′ to 100′ spans.

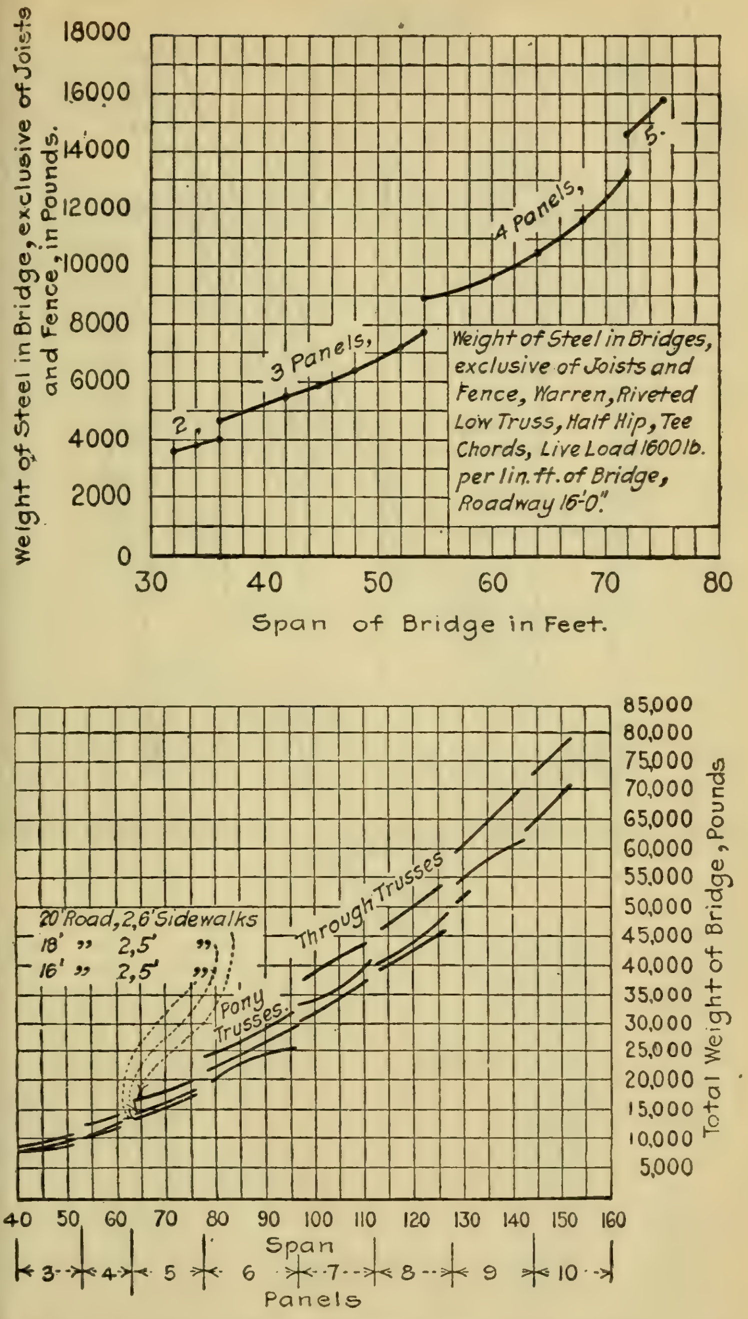
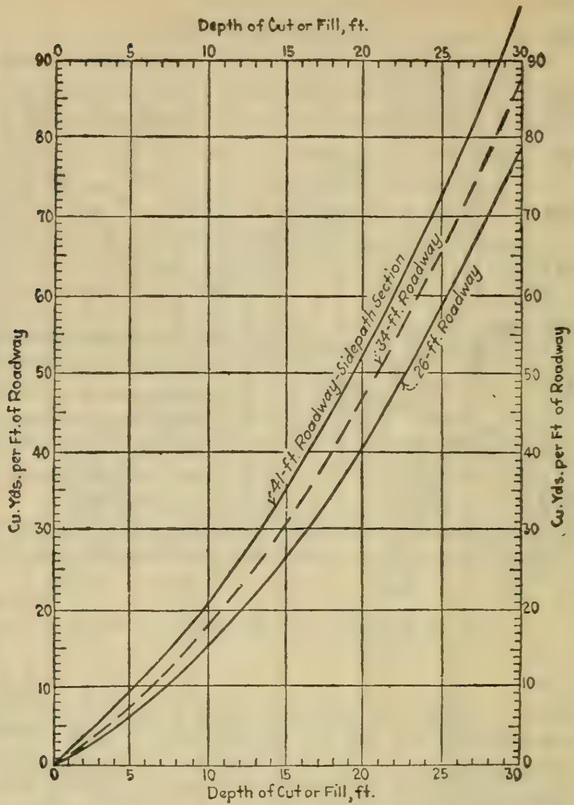


FIG. 264.—Typical weights old style light, steel bridges. Plank floors. Approx. 100 lbs. per sq. ft. live loads.



Graphic for estimating road approach earthwork grade crossin eliminations.

Table 126.—Unit Prices, 1925

Maine

Description	Unit	Number of Bids	Average
arth excavation	Cu. yd.	16	$ 1.19
ock excavation	Cu. yd.	14	4.11
orrow	Cu. yd.	16	1.23
;one fill	Cu. yd.	8	2.34
ravel base	Cu. yd.	9	2.31
;one base, gravel finish	Cu. yd.	9	2.64
one base, crushed-stone finish	Cu. yd.	4	3.96
ravel subbase	Cu. yd.	13	2.35
one V-drain	Cu. yd.	1	2.80
de underdrain	Cu. yd.	2	2.65
ass A concrete	Cu. yd.	15	30.27
ass B concrete	Cu. yd.	16	27.69
ement rubble masonry	Cu. yd.	1	$15.00
p-rap	Lin. ft.	1	3.00
ying 12″ corrugated metal pipe	Lin. ft.	15	0.83
ying 14″ corrugated metal pipe	Lin. ft.	11	0.88
ying 16″ corrugated metal pipe	Lin. ft.	11	1.10
ying 18″ corrugated metal pipe	Lin. ft.	10	1.22
ying 20″ corrugated metal pipe	Lin. ft.	5	1.38
ying 24″ corrugated metal pipe	Lin. ft.	8	1.52
ying 12″ cast-iron pipe	Lin. ft.	2	1.00
ying 16″ cast-iron pipe	Lin. ft.	9	1.50
ying 18″ cast-iron pipe	Lin. ft.	7	1.68
ying 24″ cast-iron pipe	Lin. ft.	6	1.87
ying 30″ cast-iron pipe	Lin. ft.	2	3.00
:op inlets	Each	6	57.50
bble gutters	Sq. yd.	8	1.44
avel road	Cu. yd.	11	2.61
ushed-stone base course	Cu. yd.	5	4.83
tuminous-macadam surface course	Cu. yd.	8	5.64
tuminous-material applied (cars)	Gal.	8	0.10
tuminous-material applied (barrels)	Gal.	8	0.075
rtland-cement-concrete pavement	Cu. yd.	3	12.17
vement reinforcing	Lb.	3	0.0433
ood guard rail	Lin. ft.	14	0.59
ire-fence guard rail	Lin. ft.	2	0.75
ying 12″ vitrified pipe	Lin. ft.	1	0.75
ying 16″ vitrified pipe	Lin. ft.	1	1.00

New Hampshire

Average Unit Bidding Prices 1925

Items	Quantities	Average Bid
rth excavation	Cu. yd.	$ 1.36
ructure excavation	Cu. yd.	3.33
rrow	Cu. yd.	1.39
avel borrow for shoulders	Cu. yd.	2.07
dge	Cu. yd.	4.19
undation-course gravel	Cu. yd.	2.22
undation-course field stone	Cu. yd.	3.28
arifying	Cu. yd.	0.11
ttom-course gravel	Cu. yd.	2.16
ttom-course crushed gravel	Cu. yd.	2.92
ttom-course modified asphalt	Cu. yd.	....
ttom-course crushed stone	Cu. yd.	3.35
rface-course gravel	Cu. yd.	2.35
rface-course crushed gravel	Cu. yd.	3.05
rface-course modified asphalt	Cu. yd.	0.74
rface-course bituminous-macadam broken stone	Cu. yd.	4.05
rface-course reinforced concrete	Sq. yd.	2.78
rface-course trap rock	Cu. yd.	4.04
plying bituminous material	Gallon.	0.07
ncrete Class 1	Cu. yd.	27.54

Table 126—*Continued*

New Hampshire

Average Unit Bidding Prices 1925

Items	Quantities	Average B
Concrete Class 2	Cu. yd.	21.88
Cement stone masonry	Cu. yd.	14.14
Rip-rap	Cu. yd.	3.20
Cobble gutter	Cu. yd.	1.68
Laying 8″ corrugated metal pipe	Lin. ft.	1.08
Laying 12″ corrugated metal pipe	Lin. ft.	1.03
Laying 14″ corrugated metal pipe	Lin. ft.	1.02
Laying 16″ corrugated metal pipe	Lin. ft.	1.14
Laying 18″ corrugated metal pipe	Lin. ft.	1.25
Laying 20″ corrugated metal pipe	Lin. ft.	1.26
Laying 24″ corrugated metal pipe	Lin. ft.	1.63
Laying 30″ corrugated metal pipe	Lin. ft.	2.11
Wood guard rail	Lin. ft.	0.69
Cable guard rail	Lin. ft.	0.80
Reinforcing steel	Lbs.	0.09

Texas

Unclassified roadway excavation	$ 0.1
Common roadway excavation	0.
Solid-rock roadway excavation	1.
Dry-channel excavation	0.
Wet-channel excavation	0.
Excavation for culverts, Class A	0.
Excavation for culverts, Class B	1.
Excavation for culverts, Class C	3.
Excavation for bridges, Class A	1.
Excavation for bridges, Class B	2.
Excavation for bridges, Class C	6.
Borrow	0.
Stripping material pits	0.
Overhaul	0.
Road grader work	6.
Subbase complete in place	
Shell furnished, exclusive of freight, etc	0.
Crushing and screening	1.
Extra rolling base and surface courses	3.
Sprinkling	2.
Water hauled additional mile	1.
Material hauled additional quarter	0.
Gravel base course	0.
Crusher-run broken stone furnished	1.
Standard gravel surface course complete in place	0.
Double bituminous surface treatment complete in place	0.
Triple bituminous surface treatment complete in place	0.
Bituminous-macadam surface course complete in place	1.
Two-course limestone rock asphalt surface course	0.
Sheet-asphalt pavement complete in place	1.
Concrete pavement complete in place	2.
Reinforcing steel for pavements complete in place	0.
Untreated bridge timber complete in place	80.
Treated timber complete in place	110.
Class A concrete complete in place	20.
Class B concrete complete in place	20.
Class C concrete complete in place	20.
Class D concrete complete in place	23.
Reinforcing steel (structures) complete in place	0.
Structural steel complete in place	0.
Treated timber piling complete in place	1.
Precase concrete piling complete in place	5.
Wire-cable guard railing complete in place	0.
Wood guard railing complete in place	0.
Concrete railing for structures, type C complete in place	2.
Concrete railing for structures, type D complete in place	2.

TABLE 126—*Continued*

IDAHO

Solid rock, $1.16 per cubic yard.
Loose rock, 50 cts. per cubic yard.
Earth, 28 cts. per cubic yard.
Class A concrete, $28.34 per cubic yard.
Class B concrete, $27.06 per cubic yard.
Reinforcing steel, 6.5 cts. per pound.
Hand-placed rip-rap, $3.50 per cubic yard.
Loose rip-rap, $2.44 per cubic yard.
Guard rail, 78 cts. per linear foot.
Crushed rock or gravel surfacing, $1.66 per cubic yard.
Plain concrete pavement, $1.84 per square yard.
Bituminous-concrete pavement $1.67 per square yard.
Pavement subgrade preparation, 4.7 cts. per square yard.
Gravel subbase for pavement, $1.50 per cubic yard.
Crushed-gravel shoulders, $1.85 per cubic yard.
Hauling and placing galvanized-pipe culverts:
- 12″, 27 cts.
- 15″, 35 cts.
- 18″, 50 cts.
- 24″, 64 cts.
- 30″, $1.38
- 36″, $1.40

Hauling and placing concrete culvert pipe:
- 12″, 43 cts.
- 18″, 55 cts.
- 24″, 55 cts.
- 30″, 75 cts.
- 36″, $1.25

NEW MEXICO

Item	Unit	Average Unit Bid
Class 1 excavation	Cu. yd.	$ 0.296
Class 2 excavation	Cu. yd.	0.825
Class 3 excavation	Cu. yd.	2.17
Class 1 borrow	Cu. yd.	0.265
Overhaul	Sta. yd.	0.045
Clearing and grubbing, overhaul	Acre	30.00
Class A concrete	Cu. yd.	26.16
Class B concrete	Cu. yd.	25.61
Concrete 1:2:3 (structures)	Cu. yd.	20.70
Mortar rubble masonry	Cu. yd.	10.67
Rip-rap	Cu. yd.	2.50
Grouted cobble-stone apron	Cu. yd.	10.00
Spillway base course	Cu. yd.	2.17
Concrete pavement 1:2:3	Cu. yd.	14.19
Two-course crushed-rock surfacing	Cu. yd.	3.37
Two-course crushed-caliche surfacing	Cu. yd.	1.85
One-course gravel surfacing	Cu. yd.	1.70
Gravel surfacing (bridge floors)	Cu. yd.	2.89
Clay or caliche plating	Cu. yd.	0.77
18″ diameter 16 Ga. C. M. C	Lin. ft.	2.45
24″ diameter 14 Ga. C. M. C	Lin. ft.	3.09
30″ diameter 14 Ga. C. M. C	Lin. ft.	3.71
36″ diameter 14 Ga. C. M. C	Lin. ft.	3.47
24″ diameter reinforced-concrete pipe	Lin. ft.	3.50
30″ diameter reinforced-concrete pipe	Lin. ft.	5.00

UNIT PRICES BRIDGE AND GRADE-CROSSING WORK

Compiled, 1925, by W. G. Harger for Western New York Conditions

Item number	Item	Unit price
1	Clearing and grubbing	Special each case
2a	Earth excavation (borrow pit)	$ 0.70 per cubic yard
2b	Earth excavation roadway, common	0.90–1.50 per cubic yard
2c	Earth excavation foundations and culverts (dry)	2.00–2.50 per cubic yard
2d	Earth excavation foundations and culverts (wet)	4.00 per cubic yard
2e	Earth excavation slip scraper ditch work	0.75 per cubic yard
2f	Earth excavation sewers	Included in pipe price
2g	Backfill (abutments)	1.25 per cubic yard
3a	Rock excavation common roadway (shale)	2.00 per cubic yard
3aa	Rock excavation common roadway (hard)	2.50 per cubic yard
3b	Rock excavation in foundations (dry)	6.00 per cubic yard
3c	Rock excavation in foundations (wet)	8.00 per cubic yard
3d	Rock excavation removing old masonry	4.00 per cubic yard
5	Overhaul	0.007–0.01 per station yard
6	Sewer pipe	(See sewer diagrams)
7a	4″ underdrain	0.25 per linear foot
7b	6″ underdrain	0.35 per linear foot
10	Relaying old pipe	0.20 per linear foot
13a	12″ cast-iron pipe (medium weight)	3.50 per linear foot
13b	14″ cast-iron pipe (medium weight)	4.50 per linear foot
13c	16″ cast-iron pipe (medium weight)	5.70 per linear foot
13d	18″ cast-iron pipe (medium weight)	7.00 per linear foot
13e	20″ cast-iron pipe (medium weight)	8.50 per linear foot
13f	24″ cast-iron pipe (medium weight)	10.00 per linear foot
13g	30″ cast-iron pipe (medium weight)	15.00 per linear foot
13h	36″ cast-iron pipe (medium weight)	20.00 per linear foot
	Pointing old masonry	0.05 per square foot
16	Rip-rap	2.50 per cubic yard
17	Piles	0.90–1.20 per linear foot
18	Timber and lumber	80.00 per thousand
19	Portland cement	3.20 per barrel
20a	1:2:4 concrete[1] (jack arch floor)	18.00 per cubic yard
20b	1:2:4 concrete[1] (formed floor)	20.00 per cubic yard
20c	1:2:4 concrete[1] (slabs)	20.00 per cubic yard
20d	1:2:4 concrete[1] (trestle designs)	25.00 per cubic yard
21a	1:2½:5 concrete[1] foundations	10.00 per cubic yard
21b	1:2½:5 concrete[1] abutments (large work)	14.00 per cubic yard
21c	1:2½:5 concrete[1] abutments and pedestals (small)	16.00 per cubic yard
22a	1:3:6 concrete[1] pipe jackets	10.00 per cubic yard
27	Concrete[1] curbing	25.00 per cubic yard
27a	Curb bar	0.30 per linear foot
28	Concrete gutter (cement incl.)	18.00 per cubic yard
29	Cobble gutter (cement joints)	1.25 per square yard
30	Metal reinforcement concrete pavement	0.035 per square foot
31	Bar reinforcement concrete pavement	0.05 per pound
32b	Structural steel	
	Truss bridges	0.075 per pound
	Plate girders	0.07 per pound
	Rolled stringers	0.06 per pound

[1] Concrete prices do not include cement.

UNIT PRICES—*Continued*

Item number	Item	Unit price
32*a*	Bar steel (in structures)	$0.06 to $0.07 per pound
33	Miscellaneous iron and steel	0.10 per pound
33½	Corrugated iron for bridge floor jack arches	0.20 per square foot
34	Wooden guide rail	0.75 per foot
35	Cable guide rail	1.25 per foot
36	Concrete guide posts	3.25 each
37	2" pipe railing	3.00 per foot
38	Preparing fine grade	0.10 per square yard
39	Run-of-bank gravel foundation	3.00 per cubic yard
41	Field or quarry-stone foundation	4.00 per cubic yard
42	Run-of-bank gravel bottom	3.50 per cubic yard
44	Broken-slag bottom	6.00 per cubic yard
45	Broken-stone bottom	7.00 per cubic yard
46	Concrete foundation for pavement (cement not included)	7.00 per cubic yard
47	Bituminous-macadam top (bitumen not included)	9.00 per cubic yard
51*c*	Concrete pavement (cement not included)	10.00 per cubic yard
54	Brick pavement*	3.50 per square yard
55	Stone-block pavement*	5.50 per square yard
56	Trimming shoulders	0.10 per linear foot of road
61	Broken slag (loose)	4.00 per cubic yard
62	Screened gravel (loose)	3.00–4.00 per cubic yard
63	Broken stone (loose)	4.50 per cubic yard
66	Bituminous material *A* (penetration)	0.15 per gallon
71	Bituminous material *T* (penetration)	0.17 per gallon
75	Maintaining traffic	0.20 per foot
76	Resetting wooden guide rail	0.50 per foot
	Waterproofing	0.10 per square foot

* Does not include concrete base.

Miscellaneous Items

Labor raising track	$ 0.80 per linear foot per foot raise.
Pile temporary track protection during construction of railway bridges	30.00 per foot per track.

Cost of Interurban Electric Track Work

Ballast, ties, poles and wiring	$5 per ft. single track.
Steel rails	$1.50 per ft. single track.

The sample preliminary reports following illustrate the methods in common use for high-type roads covering pavements, bridges and railroad-crossing problems. Reports of this character will rarely differ from the final cost of construction by more than 15%. While photographs increase the value of these reports, they are not so essential as for new locations. Notes on photography are given on page 818.

6. Sample Preliminary Pavement Design Report

MT. MORRIS VILLAGE STATE-COUNTY HIGHWAY, LIVINGSTON COUNTY, NEW YORK STATE

"1. **Location and Length.**—The proposed improvement extends from the south corporation line at Buck Run northerly along Main Street to State Street, a distance of approximately 4800′, and on Chapel Street from Main Street to Clinton Street, a distance of approximately 400′. This construction will complete the state system through Mt. Morris Village and furnish the final connecting link between the following previously improved roads: Nos. 482, 855, 5270, and 5665.

"2. **Grades and Alignment.**—The grades are easy and the alignment straight. No grade reductions will be required nor will any rights of way be necessary to improve the alignment.

"3. **Traffic Classification (Based on Traffic Classification Map).**—This road is Class II from Stas. 0 to 26 (Buck Run to Erie Street) and on the verge between Class II and Class I from Stas. 26 to 48 (Erie Street to State Street). From Stas. 26 to 48 it lies in the business section of the village and takes all traffic to the Erie Ry. station.

"4. **Suitable Types of Pavement (in Respect to Traffic Classification).**—Between Stas. 0 and 26 (Class II traffic) either bituminous macadam or reinforced cement concrete are suitable.

"Between Stas. 26 and 48 (Class I traffic) either brick or asphaltic concrete on concrete bases or reinforced cement concrete are suitable. (For suitability of pavements see Table 2, p. 6.)

"5. **Soils.**—The subgrade soils are as follows:

Stas. 0– 4	Ordinary loam
Stas. 4– 7	Quicksand
Stas. 7– 22	Ordinary loam
Stas. 22– 48	Gravelly soil
Stas. 880–884	Gravelly soil

"6. **Equal Strength Design (Based on Tables 153, and 154, pp. 959).**—Considering the above list of soils and that the road is entirely in cut, the following depths of pavement are recommended:

TOTAL PAVEMENT THICKNESS IN INCHES

Location	Type			
	Bituminous macadam	Reinforced concrete 0.65 lb. per square foot	3″ asphaltic-concrete surface on concrete base	4″ brick on concrete base
Stas. 0– 4	13	8	10	11
Stas. 4– 7	24	8[1]	10[2]	11[2]
Stas. 7– 22	13	8	10	11
Stas. 22– 48	10	7	9	10
Stas. 880–884	10	7	9	10

[1] Bottom and top reinforcement and subbase.
[2] Gravel subbase.

"7. **Materials Available.**—Local sand and gravel fit for concrete paving base, culverts, or subbase bottom courses are available as follows:

"Gravel pit owned by village of Mt. Morris located 2000′ (downhill haul) west of Sta. 46. This gravel if screened ought to to be suitable for the coarse aggregate for concrete paving base, but is not probably good enough for concrete pavement. This pit has been sampled 7–914 and submitted to Albany for approval. The price of this gravel is 75 cts. per cubic yard at the pit. This gravel is suitable (pit run) for subbase under macadam, Stas. 0 to 22. Seven thousand cubic yards are available.

TABLE OF COMPARATIVE COSTS

1	2	3	4	5		6	7
Type	Location, Sta. to Sta.	Estimated construction cost per square yard	Interest on construction cost at 5%	Maintenance and renewal yearly charges per square yard		Maintenance[1] of shoulders, culverts, ditches, etc., per square yard of pavement[1]	Comparative total final yearly cost (sum of columns 4, 5, and 6)
				Maintenance	Renewal		
Bituminous macadam	0–26	$1.60	$0.08	$0.040	$0.12	$0.005	$0.25
Bituminous macadam	26–48	1.90	0.095	0.050	0.18[2]	0.005	0.33
Reinforced cement concrete	0–48	2.70	0.135	0.010	0.16[2]	0.005	0.32
3″ asphaltic concrete on 6″ concrete base	26–48	3.10	0.155	0.025	0.17	0.005	0.35
4″ brick, ¾″ cement-sand cushion, 5″ concrete base	26–48	4.10	0.205	0.015	0.15	0.005	0.37

[1] Based on $100 per mile divided by the number of square yards of pavement in the job.
[2] Eventually sheet-asphalt resurface.

"Sand pit, owned by Jerry Donovan, located 2 miles west of Sta. 46. Unlimited quantity. Rather uniform fine-grained sand. Field test showed 3% loam. Probably good for any grade of concrete except concrete pavement. Sample 7–913 taken and submitted to Albany for approval. Price at pit 50 cts. per cubic yard.

"Imported sand fit for any grade of concrete can be obtained from the valley sand, Pennsylvania Ry. delivery at $1.45 per ton, f.o.b. Mt. Morris. Screened gravel from the same source, $1.35 per ton, f.o.b. Mt. Morris.

"*Imported crushed limestone* acceptable for all work can be obtained from Le Roy, $2.05 per ton, f.o.b. Mt. Morris, Erie Ry. delivery.

"*Crushed slag* fit for macadam bottom course, $2.35 per ton Erie Ry. delivery.

"*Brick.*—$41.50 per 1000, f.o.b. Mt. Morris, any railroad.

"*Cement.*—$2.35, f.o.b. Mt. Morris (bags returned).

"*Water.*—Village water supply. Hydrants located at frequent intervals.

"*Old Macadam.*—In order that the new grade line be placed at the proper elevation to fit the sidewalks about 900 cu. yd. old macadam will have to be excavated. This can be screened and reused as macadam bottom course between Stas. 0 and 26.

"**8. Comparative Cost Estimates.**—The comparative cost estimates are based on the equal-strength depths recommended in Art. 6 of this report and on the material prices quoted in Art. 7 of this report. Labor at 35 cts. per hour.

"The maintenance and renewal estimates are based on modified department records (see Table 97, p. 520).

"The difference in motor operation cost for the different types of surface (see Table, p. 68) would not add over 2 cts. per square yard per year to the total yearly cost of macadam as compared with Class A surfaces, which brings the total estimated cost of the last column up to 27 cts., for bituminous macadam, Stas. 0 to 26.

"From the standpoint of both original and final cost there is a very evident advantage for macadam Stas. 0 to 26. The local people have no particular preference as to type of pavement for this portion of the road. Local preference would be the only factor entitled to modify decisions based on the cost analysis, provided the additional cost is paid locally. As this factor need not be considered, bituminous-macadam pavement is recommended from Stas. 0 to 26.

"From Stas. 26 to 48, local preference must be considered. The village proposes to pay the additional cost introduced by such preference as to type and extra width desired. Under these conditions the cost analysis is of value only as indicating proper state cooperation. Article 10 gives alternate total estimates of cost to enable the village to come to a reasonable decision as to the type they will ask for.

"**9. Recommended State and County Cooperation Based on Final Cost (Art. 8).**—The state would be justified in limiting their cooperation to the cost of 16′ bituminous-macadam pavement, Stas. 0 to 26, and an 18′ reinforced-concrete pavement, Stas. 26 to 48 and 880 to 883, with ordinary surface-drainage provisions. This would amount to approximately $35,000. This is not an excessive amount if the funds are available (see Table 7, p. 15), considering the volume of traffic served (about 1500 daily).

"I understand that the rules of the Department limit cooperation to the construction of a 16′ road of the same type already constructed outside of the village. This rule would limit cooperation to a 16′ bituminous macadam which would cost approximately $30,000 for this locality. Under these circumstances it seems desirable to set the cooperation at $30,000.

"**10. Preliminary Cost Estimates.**—The following estimates have been prepared to give the village authorities some basis for decision as to type and width. These estimates are rough preliminary figures subject to final revision after the plans are worked out in detail. They are, however, liberal and will in all probability exceed the final figures by from 10 to 15%. Sidewalks, curbing, and storm sewers are itemized separately to permit the village to estimate general and local charges. The pavement widths used have been tentatively approved by the village board and are listed as follows:

Width, feet	
18 (no curb)	Stas. 0 – 16
20 (no curb)	Stas. 16 – 26
34 (curb)	Stas. 26 – 36
34–60 (curb)	Stas. 36 – 39
60 (curb)	Stas. 39 – 48 +
40 (curb)	Stas. 880 + 37–883 + 66 –

A complete system of storm sewers is provided. The unit prices for the major items are as follows:

Adopted Unit Prices

Excavation	$1.00 cu. yd.
Gravel subbase	2.20 cu. yd.
Macadam bottom (old macadam reused)	2.50 cu. yd.
Macadam bottom (new slag)	4.80 cu. yd.
Bituminous-macadam top (limestone)	8.00 cu. yd.
Bituminous Mat. A (penetration macadam)	0.12 gal.
7″ reinforced-cement-concrete pavement	2.70 sq. yd.
3″ asphaltic concrete on 6″ cement-concrete base	3.10 sq. yd.
4″ brick, cement-sand cushion, 5″ cement-concrete base	4.10 sq. yd.
Sidewalk	0.25 sq. ft.
Curb (concrete)	0.90 lin. ft.

Alternate Total Estimates

Estimate 1

Bituminous macadam 10, 13, and 24″ thick

1. Excavation	$12,000
2. Curbing	6,000
3. Sidewalks	3,000
4. Special drainage	9,000
19,200 sq. yd. bituminous-macadam pavement at $1.90	36,000
Incidentals	3,000
Total	$69,000
State and county cooperation	30,000
Total village share	$39,000

Estimate 2

Bituminous macadam, Stas. 0 to 26.
Reinforced cement concrete, Stas. 26 to 48 and Chapel Street:

Items 1–4 (Estimate 1)	$30,000
13,600 sq. yd. reinforced-concrete pavement at $2.70	37,000
5,600 sq. yd. bituminous macadam at $1.60	9,000
Incidentals	3,000
Total	$79,000
State and county	30,000
Total village share	$49,000

Estimate 3

Bituminous macadam, Stas. 0 to 26.
3″ asphaltic concrete on 6″ concrete base, 26 to 48 Chapel Street:

Items 1–4 (Estimate 1)	$30,000
13,600 sq. yd. asphalt pavement at $3.10	42,000
5,600 sq. yd. bituminous macadam at $1.60	9,000
Incidentals	3,000
Total	$84,000
State and county cooperation	30,000
Total village share	$54,000

Estimate 4

Bituminous macadam, Stas. 0 to 26.
4" brick, cement-sand cushion, and 5" concrete base:

Items 1-4 (Estimate 1)	$30,000
13,600 sq. yd. brick pavement at $4.10	56,000
5,600 sq. yd. bituminous macadam at $1.60	9,000
Incidentals	3,000
Total	$98,000
State and county cooperation	30,000
Village total	$68,000

Signed
Designing Engineer."

Remarks.—For the interest of the reader actual procedure on this road was as follows: The contract was let for reinforced-cement-concrete pavement, Stas. 0 to 26, and brick pavement, Stas. 26 to 48, the local people paying the excess cost over and above the state-fund limit advised in the foregoing report. This was a rational solution, considering local preference and willingness to assume added cost.

PRELIMINARY INSPECTION AND DESIGN REPORT, BRIDGE 1, ROAD 767, MONROE COUNTY, TOWN OF PERINTON

"**Location.**—O. K., provided channel is straightened as per general layout and 10° skew bridge used. See page 1007, Typical Bridge Plans.

"**Waterway Area.**—Drainage area, 27 sq. miles. Probable maximum run-off 3500 sec.-ft., from natural watershed. Takes also spillway run-off from barge canal. Probable total maximum 4000 sec.-ft. High-water data very definite at the bridge. No doubt but what 500-sq. ft. flow area is about right with flood velocity about 8' per second. Old structure 42' clear span. Use 45' clear span with 2' débris clearance above 392.2 extreme maximum flood elevation.

"**Channel Improvements.**—Inlet channel needs straightening to increase flow capacity and reduce scour at southwest wing. Approximately 4000 cu. yd. of excavation are required for channel and abutments. Of this amount approximately 2500 cu. yd. are fit for road-approach fills.

"**Road-approach Grades.**—The future reconstruction grade and alignment have been worked out at this bridge. This alignment is used for the new bridge. The west approach grade agrees with the proposed future grade. There is not enough good channel excavation to raise the east approach to the future grade, so an easy run-off has been designed utilizing all the good channel excavation and making this grade as near as possible to the future grade, considering limitation of fill material. For a separate bridge job we did not feel justified in stipulating additional east approach work, which is strictly a road reconstruction charge.

"**Road-approach Pavement.**—Same type as existing pavement—gravel bottom, macadam top.

"**Bridge-foundation Conditions.**—Fine sand (almost quicksand). Piles will be needed. Figure on 30' piles. Length ordered in leads to be determined by test piles.

"**Type of Structure.**—Steel I-beam superstructure adopted as the most suitable and economical type.

"Through plate girder rejected on account possible future widening.

"Concrete T-beam design rejected on account of difficulty of forming; high abutments and soft bottom, also greater floor depth.

"Thirty foot roadway ample for long term of years. 1926 traffic count 2000 in 12 hrs. in August. Allowing for 50 years traffic growth gives approx. 4000 to 5000 vehicles in 12 hrs. A 30' bridge will easily handle 7000 to 9000 in 10 hrs. No sidewalks needed. No gas mains at bridge. Provide contingent allowance for maintaining traffic.

COST OF STRUCTURE

timated contract cost	$35,000
ıgineering and contingencies	4,000
Total appropriation	$39,000
tual final cost, allowing for bid cuts and the elimination of contingent items probably not needed about	$26,000
Engineering	2,000
Probable final cost	$28,000

COST OF PRELIMINARY ENGINEERING

rvey (Harger and Anderson)	$ 11
›rings (Anderson)	80
›sign and estimate (Harger)	68
acing (Leonard)	22
ıecking and right-of-way maps (Anderson)	60
Total	$241

= ⅔% of the estimated contract cost.

"*Equipment Required:*

Clam-shell excavator (general-utility truck crane)
Pile driver (steam or drop hammer)
1- or 2-bag batch concrete mixer
Roller
Necessary trucks, teams, and wagons
Necessary small tools, plows, scrapers, etc.
Power pump for foundation drainage.

"Materials:

Bottom-course gravel (local), short haul
Crushed-stone macadam (imported)
Concrete materials (imported)
Piles (local)
Rip-rap (local fence stone), 5-mile haul maximum.

(*Signed*)

Bridge Eng.

SAMPLE PRELIMINARY GRADE CROSSING ELIMINATION REPORT

The following report illustrates specific cases where elimination / relocation on structure seems the proper solution. Preliminary ports of this nature set the general scheme. Detail design reports 'e given in Chap. IX, page 642.

EPORT FOR CROSSING 68 GENESEE & WYOMING VALLEY RY. ROAD 5021, TOWN OF CALEDONIA, COUNTY OF LIVINGSTON, PUBLIC SERVICE CASE 3385

›sessed valuation town of Caledonia (1925)	$3,400,000
aximum permissable town share of construction cost permitting mandatory order	$ 28,000
aximum permissable total cost of elimination permitting mandatory order	$ 113,000

List of Elimination Projects in Caledonia on the State Road Syste[m] in Their Order of Importance on Completion of the State System

Order of town importance	Index map crossing number	Danger index in 1930	Road number	Railroad	Order of[1] importance of railroad in question	Approximate total estimated cost (includes property damage)
1[2]	38	24,000	5273	Penn & Erie	Penn 2	$ 105,000 to 160,0[00]
2	16	18,000	5021	Erie	2	130,000
3	93	15,000	Scottsville-S	Lehigh, M. L.	10	115,000
4[3]	68	14,000	5021	G. & W. V.	1	100,000
5	41	5,000	5021	N. Y. Central	41	180,000
6	40	4,000	5273	Erie	13	180,000
7	94	3,000	Scottsville-S	N. Y. Central	44	90,000
8	95	3,000	Scottsville-S	Erie	17	100,000
9	76	2,000	5593	G. & W. V.	2	90,000
10	180	1,000	5593	Erie	21	Road relocation
			Total	All eliminations in town	.....	$1,140,000

[1] Considers completing routes as well as relative danger.
[2] Cost will probably be reduced to $105,000 due to Erie abandonment switch.
[3] P.S. Case 3385.

Discussion.—The proper solution of Crossing 68 Public Service Case 33[85] Genesee and Wyoming Valley Ry. at Road 5021, Town of Caledon[ia] depends on the proposed treatment of three other Erie Ry. Crossi[ngs] 16, 40, 180 and two town road crossings (see attached map); that is, Cross[ing] 68 cannot be considered as an independent separate project.

There is no question but what from the standpoint of safety it is desira[ble] sometime in the future to relocate Road 5021 keeping it south of the E[rie] tracks from Crossing 16 to Road 5273 crossing the Genesee and Wyom[ing] Valley Ry. south of the Erie Junction (Crossing 68*a* on map). This relocat[ion] with one elimination 68*a* Genesee and Wyoming Valley will eliminate th[ree] state road crossings on State Touring Route 5, one crossing on State R[oad] 5593 and two town road crossings. It will reduce the crossings on travel [to] Rochester from the west by one crossing and will increase the safety at [the] remaining Crossing 40, as this crossing is much safer than any other on [the] route due to station stop, wide street, etc. When Road 5021 is relocat[ed] the first town road, about 800′ east of Crossing 16, will be left open for lo[cal] outlet; this is a comparatively safe crossing at right angles to track, w[ith] level grade and good sight distance. Crossings 16, 180, and Church Str[eet] will be closed to traffic and Crossing 68*a* eliminated by overhead bridge.

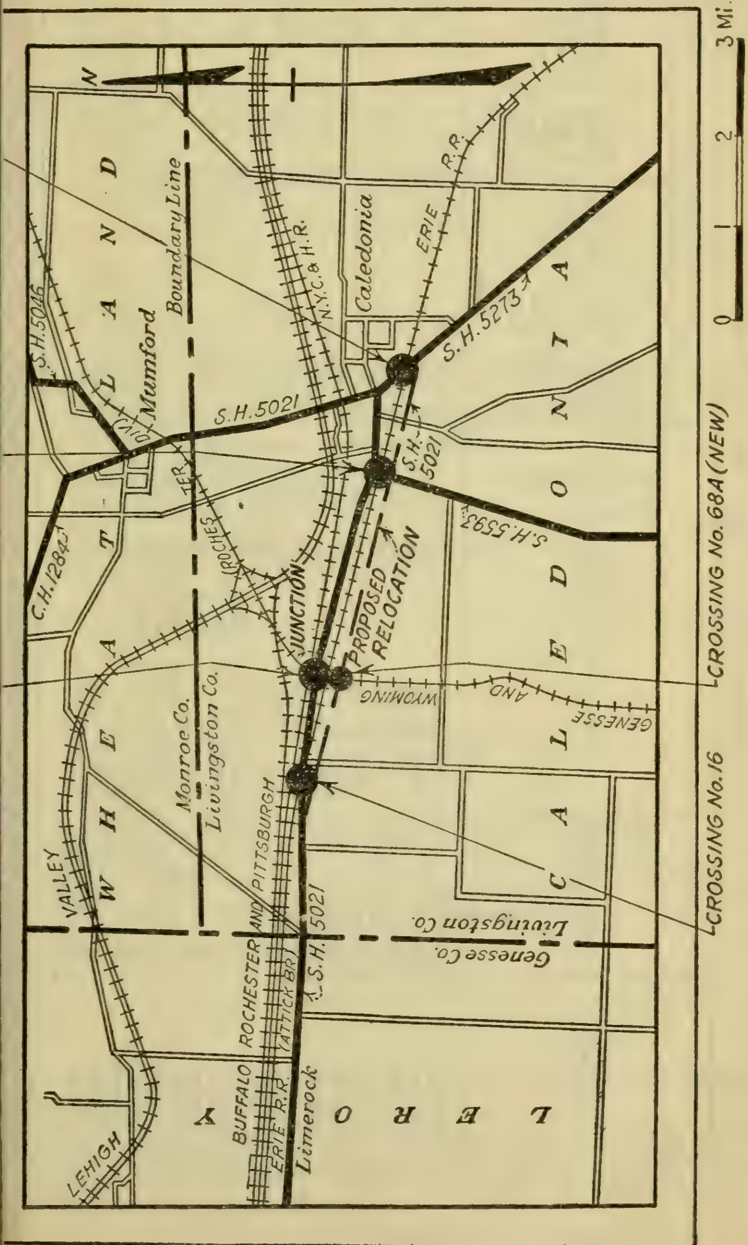
This relocation scheme will be difficult to work out immediately [but] should be worked in on reconstruction of Road 5021 and it therefore see[ms] desirable to take care of Crossings 16, 68, 40, and 180 by means of fl[ashing] signals at once which will serve very well until the relocation can be worl[ked] out.

The most important elimination needed at once in Caledonia is Crossing [38] Penn Ry. Road 5273.

At the last hearing a study was suggested of the possibility of a sh[ort] relocation of Road 5021 from Crossing 16 keeping south of the Erie tra[cks] to the junction with the G. & W. V. Ry. and making one elimination acr[oss] both Erie and G. W. at the junction coming back on Road 5021 east [of] Crossing 68. This solution seems obviously short sighted from a study of

ıp and the preceding statement of the general problem and this would ›o materially increase motor operation costs on Route 5. Increase in ›tor operation costs for year would be approximately \$12,000; capitalized lue of increased cost, approximately \$245,000.

Signed
Grade Crossing Engineer
Div. No 4



Map to accompany report on elimination of crossing No. 68.

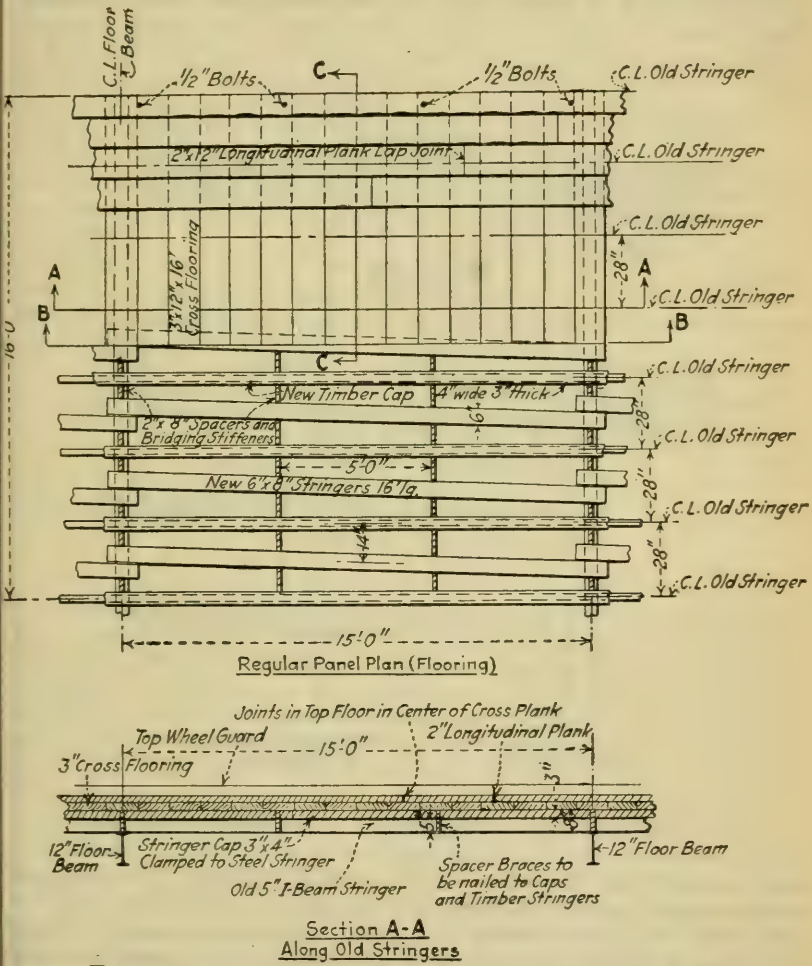
TABULATION ONTARIO COUNTY TOWN ROAD BRIDGES (ESTIMATED SAFE LOADS)
INSPECTED JULY, 1926, W. G. HARGER

	Town	Bridge name	Stream	Span, feet	Length, feet	Roadway width, feet	Age (years)	Approximate safe gross vehicle load, tons: Stringers, total vehicle load, tons	Floor beams, tons	Floor beam hangers, tons	Trusses (1 truck only), tons	Estimated safe gross vehicle load of structure, July, 1926, factor of safety 4, in tons
1	Gorham.......	Shuman	Flint Creek	62.5	12.5	16	50	2	2½	4	6½	2
2	Gorham.......	State Road	Flint Creek	45	15	18	30	4½	6	..	10	4½
3	Gorham.......	Lake to Lake	Flint Creek	54	13.5	16	30	3	5	..	6½	3
4	Gorham.......	Gizzardville	Flint Creek	66	13.3	16	40	2½	3	8	8	2½
5	Seneca........	Charlton	Flint Creek	64	12.8	14	40	2½	3	7	6½	2½
6	Seneca........	Gristmill	Flint Creek	52	13	13	50	2	3	4	3½	2
7	Seneca........	Vogt	Flint Creek	52	13	14	30	3	4	6	8	3
8	Seneca........	Otley	Flint Creek	46	11.5	15	50	7	4½	6	4½	4½
9	Phelps........	Orleans	Flint Creek	64	12.8	16	40	4½	4	5	7½	4
10	Phelps........	Wheat	Flint Creek	48	12	16	30	3½	4	..	10	4
11	Phelps........	Avery	Canandaugua Creek	72.5	1.45	12	40	2½	3	8	8½	2½
12	Phelps........	Miller	Canandaugua Creek	93+56	13.4	16	50	3	5	8	9	3
13	Phelps........	Banester	Canandaugua Creek	93	9.7	16	60	2	2½	6	4	2
14	Phelps........	Holbrook	Canandaugua Creek	109	12.8	16	40	3½	5	10	8	3½
15	Phelps........	Cuddeback	Canandaugua Creek	100	11	12	60	2	2	3	1½	1½
16	Phelps........	Mott	Canandaugua Creek	90	12.8	12	50	⅛	3	6	8	⅛
17	Phelps........	Mott 2	Mill Race	52	.....	12	60	⅛	...	..	....	Worthless
18	Phelps........	O'Brien	Flint Creek	76	12.5	16	30	5½	6	12	12	5½
19	Phelps........	Strowbridge Glen Bridge	Grimes Creek	33/9	11.0	14	20	5½	6	13	13½	5½

NOTE.—It is impossible to estimate the exact strength of these old bridges due to badly rusted steel. The results given are for a [illegible] measured with an arbitrary reduction of from 20 to 50% for deter-

CONDEMNATION AND TEMPORARY REPAIR OF WEAK BRIDGES

The determination of safe load for old bridges is a very difficult matter due to uncertainty as to the condition of old steel and timber. The reduction in strength of standard shapes due to



Typical bridge floor repair and strengthening road 485.
(Details of repair continued on page 780.)

age and fatigue is so indefinite that very conservative assumptions should be made and a large factor of safety used.

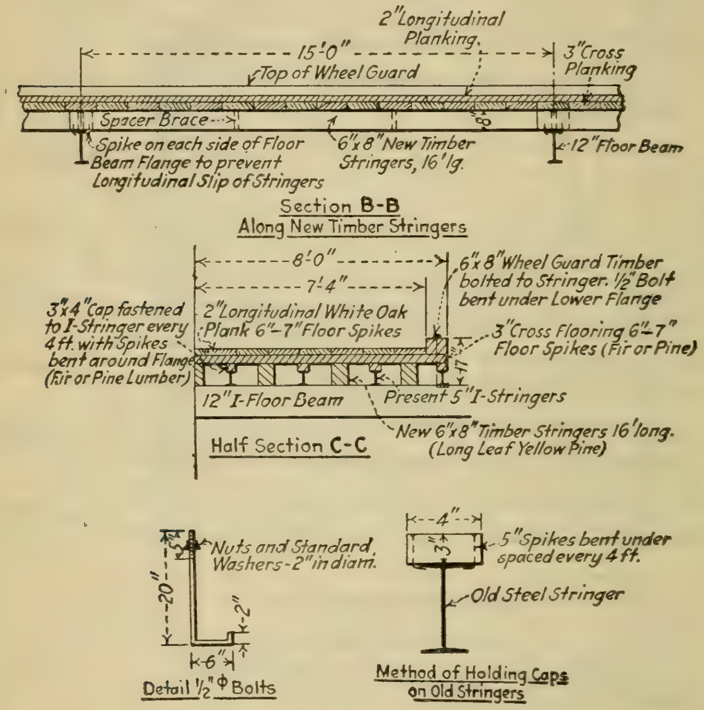
In computing safe loads for old bridges the structure should be very carefully examined and measured up for condition of floor planking, stringers, and their connections; floor beams and connections, and all truss members.

As a general rule, old steel bridges are weakest in the items of stringers, somewhat stronger for the floor beam design and floor

beam hangers, and the strongest generally in the trusses (see table page 778 giving the analysis of a number of old bridges inspected in 1926).

This general condition of relative weakness makes it possible in many cases to quite materially increase strength without complete rebuilding by strengthening the floor system.

For the effect of depth and type of flooring on distribution of wheel loads to stringers, see Chap. XIV, page 1042. Chapter XIV



Typical bridge floor repair and strengthening road 485.

also contains all necessary tables for computing safe loads on stringers, floor beams, hangers, etc. (see pp. 1026 to 1087).

Sketch Rd 485 shows a typical temporary repair which reduces impact by the use of double flooring, increases stringer strength by the use of additional timber stringers, and reduces noise by timber stringer caps. In this particular case new floor beam hangers were not required nor was it necessary to strengthen trusses by supporting bents.

MEMORANDUM FOR H. E. SMITH: REPAIR OF BRIDGE 1, ROAD 485, TOWNS OF BLOOMFIELD AND LIMA, COUNTIES OF ONTARIO AND LIVINGSTON

Pursuant to your request of recent date, Bridge 1 Sta. 0 + 00 Road 485 was inspected by W. G. Harger and R. W. Anderson on May 25, 1926.

Recommendation.—We recommend that the floor on this bridge be rebuilt at once, that the diagonal tension members and cross-braces be tightened up at once, and that the bridge be replaced with a new modern structure as soon as funds become available.

The life of the existing bridge can be increased by proper floor construction which will reduce the impact of rapidly moving road vehicles. Sketch of suggested floor construction is attached (pages 779–780.)

We also recommend that this bridge be posted for 6 tons gross load after the floor has been repaired or for a gross load of 2 tons in its present condition and that a speed limit of 5 miles per hour be required for loads of over 2 tons gross weight.

(*Signed*)
W. G. Harger
May 25, 1926.

PRELIMINARY INVESTIGATIONS FOR ROADS IN PIONEER DISTRICTS

Reports of this nature cannot be figured so accurately as for high-type roads, but if carefully done should not vary over 25% from the final construction cost. The cost of preliminary investigations depends very largely on the character of the country, the methods employed, and the travel necessary to get to the work, and will range from $2 to $40 per mile. A fair average cost for work similar to that done by the U. S. Office of Public Roads in the mountainous districts of the West is $10 per mile for ordinary cases and $30 per mile for a plane table sketch survey in difficult country.

Ordinary Preliminary Investigations.—The improvement to be investigated generally consists of a combination of betterments of existing roads with a large percentage of relocation of the old road or the new location of a highway where no road of any kind traverses the territory. The length of these projects ranges from 5 to 150 miles. The engineer generally receives orders to report on the best general route and approximate cost of a road between definite terminals, which requires more general investigation than that called for in the preliminary reports on the high-type roads previously discussed.

The field work is usually done by one or two men on foot or on horseback. All possible different routes are examined. As a rule. this general examination eliminates all but one or two possibilities, which are examined with care, sufficient notes, photographs, etc., being taken to make a reasonably close estimate of cost.

The selection of general route is based on a comparison of the following factors for the different routes:

1. Best location for the development of the country.
2. Longest open season for use.
3. Least rise and fall.
4. Feasible ruling grades.
5. Length and cost.

The following engineering equipment will cover all requirements for obtaining the general data and the detailed information required for a reasonably close cost estimate.

2 aneroid barometers $2\frac{1}{2}$ or 3″ dial in leather carrying cases. Tested for range of altitude needed.
1 Abney level reading to degrees and per cent.
1 pocket compass 2″ floating card dial or, if desired,
1 prismatic compass (card dial preferred).
1 4A Kodak with folding tripod.
Notebooks, existing maps, etc.

In rolling topography it makes no difference in which direction the line is traced, but where elevation is developed on a ruling grade the work should be done from the highest point downhill.

Where aneroid elevations must be depended on, considerable care must be exercised. If one aneroid can be left at a stationary point and its fluctuations read at intervals during the day, very accurate results can be obtained when the field aneroid is corrected for the fluctuations, but this is not feasible for work of this kind, as a rule, and aneroid elevations are, to say the least, uncertain. Where used, two instruments should be carried; when reading they should be held horizontal and the crystal rapped sharply with the finger nail to free the needle if caught, which often happens. Any important elevations should be determined at least twice, and a return trip made to the original datum point to check the instrument.

The general rise and fall can be determined by the aneroids.

The approximate location of the road for different ruling grades can be traced with the Abney level.

A rough traverse can be run with the pocket compass or prismatic compass.

Distances can be obtained by pacing (pedometer or hand counter) by timing if on horseback, by scaling from reliable maps, or by autometer if on an existing road.

Cross-sections are determined by the Abney level and are taken and recorded at sufficient intervals to show the general slope of the side hill.

Classification of excavation and the cut slopes at which excavation will stand depends on the judgment of the engineer but must be systematically recorded.

Drainage should be carefully estimated, particularly the larger structures, as this item forms a large percentage of the cost of low-type roads.

Clearing and grubbing are recorded by section.

Each engineer has his own ideas about notes and it makes little difference how the data are recorded so long as they are clearly and

definitely set down in such a way that anyone can retrace the route and reestimate the cost without additional field work.

The main faults of reports and notes are that they are not sufficiently clear on facts; they generally run strong on generalities and judgment and are not worth the paper they are written on if the author is not available to explain in detail.

A well-arranged report should either summarize the conclusions at the beginning and explain in detail later or be indexed so that the conclusions can be readily located. A preliminary estimate should be rounded out to even figures, as amounts figured to single yards or costs figured to odd figures of less amount than 10% of the total cost are merely ridiculous and show that the estimator has lost track of the relative accuracy of his work.

The following form of notes serves in a satisfactory way when supplemented by photographs, sketches, and text descriptions.

Detail suggestions on photography are given on page 818.

Tables 128 and 129 (pp. 786 and 795) serve to give a rough approximation of the amount of excavation required.

Drainage costs can be estimated on the standard structures required by the state or government for whom the work is being done or can be approximated by reference to the various standard structures and costs shown in Chap. IV and Table 133 (p. 797). Various miscellaneous information convenient for preliminary estimates are given on page 796. A rough approximation of magnetic declination can be determined from the isogonic charts (pp. 800 to 806).

Explanation of Table 128 (Pages 786 to 793)

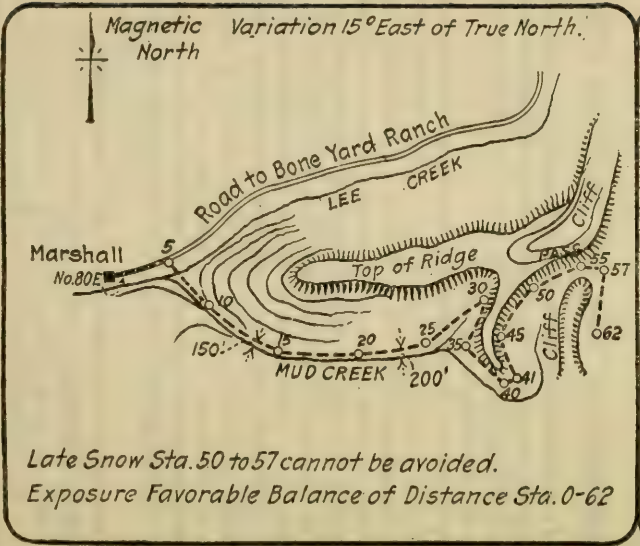
NOTE.—Quantities determined graphically, using one-way crown for single-track roads on all cross-slopes; the two-way crown for double-track roads on cross-slopes of 5, 10, and 15° and the one-way crown on cross-slopes above 15°.

If for any reason it is desired to use a two-way crown on single-track roads for cross-slopes below 15°, reduce the quantities shown in the table by about 25%. For the use of a two-way crown above 15° cross-slope, special computations will have to be made.

To illustrate the use of this table the approximate excavation for the notes shown in Fig. 265 (p. 784) will be figured.

From Stas. 0 to 5 the natural side or cross-slope of the ground is given as 5°. In this case a turnpike section can be used, say T-12. Turn to page 786 and under Sec. T-12 for a 5° cross-slope the excavation is given as 33 cu. yd. per 100′, or 165 cu. yd. for 500 ft. This will be increased 20% according to judgment for profile inequalities which gives 200-cu. yd. earth excavation from Stas. 0 to 5.

From Stas. 5 to 10 there is a 15° cross-slope. Suppose an estimate for a minimum-width single-track road S-10 is being figured. Look on page 787, and for a cross-slope of 15° and a cut slope of 1:1 the table gives 46 cu. yd. per 100′, or 230 cu. yd. for 500′. Increase this by, say, 20% for inequalities in profile, which gives 276 cu. yd. Estimate the percentage of this classed as rock,



Notes on the Marshall Wind Cave Road.

Sta. to Sta	Bearing.	Profile Grade.	Side Slope.	Classification	Cut Slope.	Aneroid Elev.	Drainage
0 - 5	N. 80° E.	+ 1%	5°	Earth	1½:1	9000	18" Pipe
5 - 10	S. 20° E.	+ 5%	15°	Earth & Boulders	1:1	9020	10' Br.
10 - 15	S. 25° E.	+ 7%	20°	" "	1:1	9050	2 (12" Pipe)
15 - 20	S. 80° E.	+ 7%	25°	" "	1:1	9090	4' x 4' Box
20 - 25	N. 80° E.	+ 7%	35°	" "	1:1	9130	2 (15" Pipe)
25 - 30	N. 45° E.	+ 7%	50°	Rock Ledge	¼:1	9160	——

REMARKS: Survey made July 15, 1918 in Company with Louis Izenton Forest Ranger. Distances paced Elevation of Marshall assumed 9000.

Clearing Sta. 0 - 15 Light Sage Brush.
15 - 30 Scrub Oak.
30 - 62 Thick Scrub Oak.

FIG. 265.

say, 10%, and the result is 250 cu. yd. for common excavation and 26 cu. yd. of solid rock.

In a similar way estimate Stas. 10 to 20.

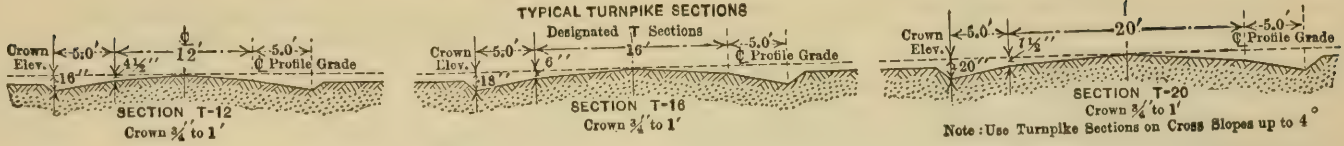
From Stas. 20 to 25 the notes record a ground cross-slope of 35°. This calls for a retaining-wall section (see p. 792), Sec. W-8 for a 35° cross-slope. The table gives the following quantities for 100′: 55 cu. yd. of wall masonry, 100 cu. yd. of excavation.

Multiply this by 5 for 500′, add a percentage for inequalities of profile, and estimate per cent of solid rock.

From Stas. 25 to 30 the notes show a rock ledge with a face slope of 50°. This calls for a section benched out of the solid ledge. See page 793, use Sec. S-8, the minimum single-track section for a cross-slope of 50°, which gives 350 cu. yd. Rock excavation per 100′, or 1750 cu. yd. for 500′.

If turnout sections for passing rigs are desired, figure the excess quantities by referring to the parts of the table dealing with the double-track widths.

TABLE 128.—BALANCED TURNPIKE SECTIONS USING T-12, T-61, AND T-20

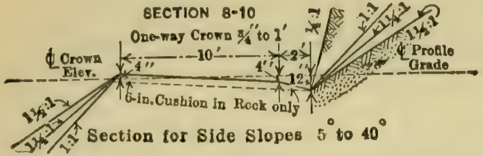


NOTE.—Add from 10% to 50% to the following quantities for inequalities in profile requiring through cuts and fills. These sections are recommended only when the natural cross ground slope is 4° or less.

Natural Ground Surface Cross Slope		Approximate Excavation per 100′ and per mile for T-12, T-16 and T-20					
		Section T-12		Section T-16		Section T-20	
Degrees	Per Cent.	Cu.yd. per 100′	Cu.yd. per mile	Cu.yd. per 100′	Cu.yd. per mile	Cu.yd. per 100′	Cu.yd. per mile
Level	0%	20 cu. yd.	1050 cu. yd.	24 cu. yd.	1250 cu. yd.	35 cu. yd.	1850 cu. yd.
5°	9%	33 " "	1750 " "	41 " "	2150 " "	59 " "	3100 " "
10°	18%	66 " "	3500 " "	90 " "	4800 " "	115 " "	6100 " "

NOTE.—For light scraper work of this kind 1.3 yd. of excavation are assumed to make 1 cu. yd. of fill This ratio is used in computing the balanced sections in this table.

Table of Approximate Quantities Balanced Sidehill Sections Mountain Roads Using Section S-10
(Single Track)



NOTE.—Add from 10% to 50% to the following quantities for inequalities in profile due to the alignment not exactly following the grade contour. An addition of 25% is normally about right for moderately rough country. Good judgment in this matter can only be developed by comparing the results obtained from this table with actual finished location designs.

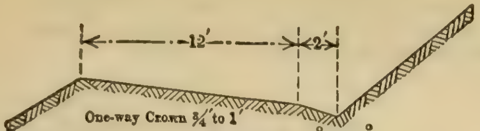
Natural Ground Cross Slope		Approximate Excavation per 100′ and per Mile for Different Cut and Fill Slopes																							
Deg.	Per Cent.	Cut Slope	Fill Slope	Cu. yd. per 100′	Cu. yd. per mile	Cut Slope	Fill Slope	Cu. yd. per 100′	Cu. yd. per mile	Cut Slope	Fill Slope	Cu. yd. per 100′	Cu. yd. per mile	Cut Slope	Fill Slope	Cu. yd. per 100′	Cu. yd. per mile	Cut Slope	Fill Slope	Cu. yd. per 100′	Cu. yd. per mile	Cut Slope	Fill Slope	Cu. yd. per 100′	Cu. yd. per mile
5°	9%	1½:1	1½:1	18	980	1¼:1	1½:1	17	900	1:1	1½:1	16	850	¾:1	1½:1	14	740	½:1	1¼:1	13	690	¼:1	1:1	12	630
10°	18%	1½:1	1½:1	34	1800	1¼:1	1½:1	31	1650	1:1	1½:1	30	1600	¾:1	1½:1	26	1400	½:1	1¼:1	22	1150	¼:1	1:1	21	1100
15°	27%	1½:1	1½:1	53	2800	1¼:1	1½:1	49	2600	1:1	1½:1	46	2400	¾:1	1½:1	42	2200	½:1	1¼:1	35	1850	¼:1	1:1	27	1450
20°	36%	1½:1	1½:1	90	4800	1¼:1	1½:1	80	4200	1:1	1½:1	70	3700	¾:1	1½:1	63	3300	½:1	1¼:1	49	2550	¼:1	1:1	42	2250
25°	47%	....	....	...	.....	1¼:1	1½:1	137	7200	1:1	1½:1	115	6100	¾:1	1½:1	97	5100	½:1	1¼:1	70	3700	¼:1	1:1	59	3150
30°	58%	....	....	...	.....	....	....	...	.....	1:1	1½:1	200	10800	¾:1	1½:1	155	8200	½:1	1¼:1	104	5500	¼:1	1:1	80	4250
35°	70%	....	....	...	.....	....	....	...	.....	....	....	...	.....	....	....	...	.....	½:1	1¼:1	155	8200	¼:1	1:1	100	5300
40°	84%	....	....	...	.....	....	....	...	.....	....	....	...	.....	....	....	...	.....	....	....	...	.....	¼:1	1:1	155	8200

As a general rule a retaining wall section should be used when the natural ground surface cross slope exceeds 30°, except for a solid rock fill which can be used up to a 40° slope.

These balanced sections are computed on the basis that 1.2 cu. yd. of earth excavation will make 1.0 cu. yd. of fill.

Where the cut slopes will stand ½:1 or ¼:1 we have assumed that there is sufficient rock so that 1.0 cu. yd. of excavation will make 1.0 cu. yd. of fill allowing for some rock waste that will occur.

Table of Approximate Quantities Balanced Sidehill Sections Mountain Roads Using Sect2 (Single Tracks)



Section for Side Slopes of 5° to 40°

Note.—Add from 10% to 50% to the following quantities for inequalities in profile due to the alignment not exactly following the grade contour. An addition of 25% is normally about right for moderately rough country. Good judgment in this matter can only be developed by comparing the results obtained from this table with actual finished location designs.

Natural Ground Cross Slope		Approximate Excavation per 100′ and per mile for Different Cut and Fill Slopes (S-12)																							
Deg.	Per Cent.	Cut Slope	Fill Slope	Cu. Yd. per 100′	Cu. Yd. per Mile	Cut Slope	Fill Slope	Cu. Yd. per 100′	Cu. Yd. per Mile	Cut Slope	Fill Slope	Cu. Yd. per 100′	Cu. Yd. per Mile	Cut Slope	Fill Slope	Cu. Yd. per 100′	Cu. Yd. per Mile	Cut Slope	Fill Slope	Cu. Yd. per 100′	Cu. Yd. per Mile	Cut Slope	Fill Slope	Cu. Yd. per 100′	Cu. Yd. per M
5°	9%	1½:1	1½:1	20	1100	1¼:1	1½:1	18	980	1:1	1½:1	17	900	¾:1	1½:1	15	790	½:1	1¼:1	13	690	¼:1	1:1	12	630
10°	18%	1½:1	1½:1	41	2200	1¼:1	1½:1	40	2100	1:1	1½:1	38	2000	¾:1	1½:1	35	1850	½:1	1¼:1	27	1450	¼:1	1:1	25	1350
15°	27%	1½:1	1½:1	68	3600	1¼:1	1½:1	66	3500	1:1	1½:1	63	3300	¾:1	1½:1	60	3100	½:1	1¼:1	46	2450	¼:1	1:1	41	2200
20°	36%	1½:1	1½:1	120	6300	1¼:1	1½:1	105	5500	1:1	1½:1	94	5000	¾:1	1½:1	85	4500	½:1	1¼:1	65	3400	¼:1	1:1	60	3200
25°	47%	.....	.....	...	.....	1¼:1	1½:1	180	9500	1:1	1½:1	145	7700	¾:1	1½:1	130	6900	½:1	1¼:1	94	5000	¼:1	1:1	78	4100
30°	58%	.....	.....	...	.....	.....	.....	...	.....	1:1	1½:1	270	14200	¾:1	1½:1	210	11100	½:1	1¼:1	145	7700	¼:1	1:1	110	5800
35°	70%	.....	.....	...	.....	.....	.....	...	.....	.....	.....	...	.....	.....	.....	...	.....	½:1	1¼:1	220	11600	¼:1	1:1	140	7400
40°	84%	.....	.....	...	.....	.....	.....	...	.....	.....	.....	...	.....	.....	.....	...	.....	.....	.....	...	.....	¼:1	1:1	215	11400

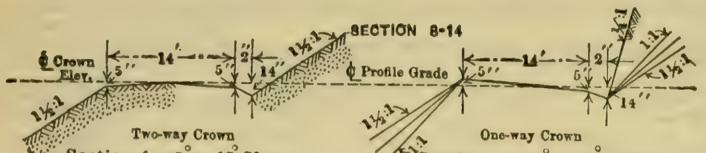
Note.—The apparent discrepancy in relative quantities of Sections S-12 and S-14 for side slopes of 5°, and 15° is due to the use of the one way crown for these slopes on single track roads and the two way crown for double track roads.

As a general rule a retaining wall section should be used when the natural ground surface cross slope exceeds 30°, except for a solid rock fill which can be used up to a 40° slope.

These balanced sections are computed on the basis that 1.2 cu. yd. of earth excavation will make 1.0 cu. yd of fill.

Where the cut slopes will stand ½:1 or ¼:1 we have assumed that there is sufficient rock so that 1.0 cu. yd. of excavation will

TABLE OF APPROXIMATE QUANTITIES BALANCED SIDEHILL SECTIONS MOUNTAIN ROADS SECTION S-14
(Double Track)



Section for 5° to 15° Slopes

Section for 15° to 40° Slopes

NOTE.—Add from 10% to 50% to the following quantities for inequalities in profile due to alignment not exactly following the grade contour. An addition of 25% is normally about the right value for moderately rough country.

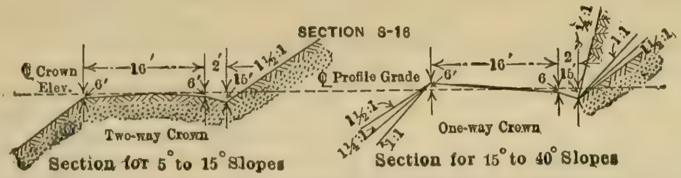
Natural Ground Cross Slope		Approximate Excavation per 100′ and per mile for Different Cut and Fill Slopes (S-14)																							
Deg.	Per Cent.	Cut Slope	Fill Slope	Cu. Yd. per 100′	Cu. Yd. per Mile	Cut Slope	Fill Slope	Cu. Yd. per 100′	Cu. Yd. per Mile	Cut Slope	Fill Slope	Cu. Yd. per 100′	Cu. Yd. per Mile	Cut Slope	Fill Slope	Cu. Yd. per 100′	Cu. Yd. per Mile	Cut Slope	Fill Slope	Cu. Yd. per 100′	Cu. Yd. per Mile	Cut Slope	Fill Slope	Cu. Yd. per 100′	Cu. Yd. per Mile
5°	9%	1½:1	1½:1	20	1100	1¼:1	1½:1	18	950	1:1	1½:1	17	900	¾:1	1½:1	15	790	½:1	1¼:1	13	690	¼:1	1:1	12	630
10°	18%	1½:1	1½:1	41	2200	1¼:1	1½:1	38	2000	1:1	1½:1	35	1900	¾:1	1½:1	33	1700	½:1	1¼:1	24	1300	¼:1	1:1	22	1200
15°	27%	1½:1	1½:1	75	4000	1¼:1	1½:1	68	3600	1:1	1½:1	63	3300	¾:1	1½:1	55	2900	½:1	1¼:1	45	2400	¼:1	1:1	40	2200
20°	36%	1½:1	1½:1	150	7900	1¼:1	1½:1	132	7000	1:1	1½:1	115	6100	¾:1	1½:1	105	5600	½:1	1¼:1	85	4500	¼:1	1:1	78	4100
25°	47%	.....	.....	...	.....	1¼:1	1½:1	220	11700	1:1	1½:1	190	10200	¾:1	1½:1	163	8600	½:1	1¼:1	118	6200	¼:1	1:1	96	5100
30°	58%	.....	.....	...	.....	.....	.....	...	.....	1:1	1½:1	370	19600	¾:1	1½:1	300	15800	½:1	1¼:1	185	9800	¼:1	1:1	137	7200
35°	70%	.....	.....	...	.....	.....	.....	...	.....	...	.....	...	.....	.....	.....	...	.....	½:1	1¼:1	275	14600	¼:1	1:1	180	9500
40°	84%	.....	.....	...	.....	.....	.....	...	.....	...	.....	...	.....	.....	.....	...	.....	.....	.....	...	.....	¼:1	1:1	270	14300

As a general rule a retaining wall section should be used when the natural ground slope exceeds 30°, except for solid rock fill which can be used up to 40° slope.

These balanced sections are computed and balanced on the basis that 1.2 cu. yd. of excavation will make 1 cu. yd. of fill.

Where the cut slopes will stand at ½:1 or ¼:1 we have assumed that 1 cu. yd. of excavation will make 1 cu. yd. of fill allowing for rock waste that will probably occur.

Table of Approximate Quantities Balanced Sidehill Sections Mountain Roads Using Section S-16



Section for 5° to 15° Slopes
Section for 15° to 40° Slopes

NOTE.—Add from 10% to 50% to the following quantities for inequalities in profile due to alignment not exactly following the grade contour. An addition of 25% is normally about right for moderately rough country. Good judgment in this matter can only be developed by comparing the results obtained from this table with actual finished location designs.

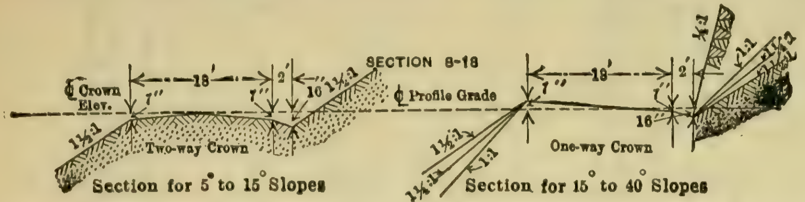
Natural Ground Cross Slope		Approximate Excavation per 100′ and per Mile for Different Cut and Fill Slopes (S-16)																							
Deg.	Per Cent.	Cut Slope	Fill Slope	Cu. Yd. per 100′	Cu. Yd. per Mile	Cut Slope	Fill Slope	Cu. Yd. per 100′	Cu. Yd. per Mile	Cut Slope	Fill Slope	Cu. Yd. per 100′	Cu. Yd. per Mile	Cut Slope	Fill Slope	Cu. Yd. per 100′	Cu. Yd. per Mile	Cut Slope	Fill Slope	Cu. Yd. per 100′	Cu. Yd. per Mile	Cut Slope	Fill Slope	Cu. Yd. per 100′	Cu. Yd. per Mile
5°	9%	1½:1	1½:1	27	1430	1¼:1	1½:1	26	1380	1:1	1½:1	25	1330	¾:1	1½:1	24	1270	½:1	1¼:1	19	1000	¼:1	1:1	18	950
10°	18%	1½:1	1½:1	54	2850	1¼:1	1½:1	51	2700	1:1	1½:1	47	2500	¾:1	1½:1	44	2300	½:1	1¼:1	32	1700	¼:1	1:1	30	1600
15°	27%	1½:1	1½:1	95	5000	1¼:1	1½:1	89	4700	1:1	1½:1	82	4300	¾:1	1½:1	75	4000	½:1	1¼:1	62	3300	¼:1	1:1	56	3000
20°	36%	1½:1	1½:1	195	10300	1¼:1	1½:1	170	9000	1:1	1½:1	150	7900	¾:1	1½:1	137	7200	½:1	1¼:1	106	5600	¼:1	1:1	92	4850
25°	47%	.....	.....	...	.....	1¼:1	1½:1	292	15400	1:1	1½:1	241	12800	¾:1	1½:1	200	10600	½:1	1¼:1	150	7800	¼:1	1:1	125	6600
30°	58%	.....	.....	...	.....	.....	.....	...	.....	1:1	1½:1	466	24600	¾:1	1½:1	368	19500	½:1	1¼:1	230	12100	¼:1	1:1	166	8800
35°	70%	.....	.....	...	.....	.....	.....	...	.....	...	.....	...	.....	.....	.....	...	.....	½:1	1¼:1	365	19300	¼:1	1:1	227	12000
40°	84%	.....	.....	...	.....	.....	.....	...	.....	...	.....	...	.....	.....	.....	...	.....	.....	.....	...	.....	¼:1	1:1	350	18500

As a general rule a retaining wall section should be used when the natural ground slope exceeds 30°, except for solid rock fill which can be used up to 40° slope.

These balanced sections are computed and balanced on the basis that 1.2 cu. yd. of excavation will make 1 cu. yd. of fill.

Where the cut slopes will stand at ½:1 or ¼:1 we have assumed that 1 cu. yd. of excavation will make 1 cu. yd. of fill allowing for rock waste that will probably occur.

Approximate Quantities Balanced Sidehill Sections Mountain Roads Using Section S-18



NOTE.—Add from 10% to 50% to the following quantities for inequalities in profile due to alignment not exactly following the grade contour. An addition of 25% is normally about right for moderately rough country. Good judgment in this matter can only be developed by comparing the results obtained from this table with actual finished location designs.

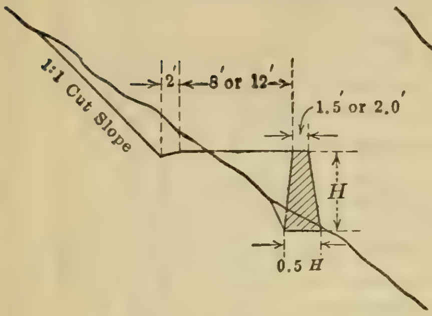
Natural Ground Cross Slope		Approximate Excavation per 100′ and per Mile for Different Cut and Fill Slopes (S-18)																							
Deg.	Per Cent.	Cut Slope	Fill Slope	Cu. Yd. per 100′	Cu. Yd. per Mile	Cut Slope	Fill Slope	Cu. Yd. per 100′	Cu. Yd. per Mile	Cut Slope	Fill Slope	Cu. Yd. per 100′	Cu. Yd. per Mile	Cut Slope	Fill Slope	Cu. Yd. per 100′	Cu. Yd. per Mile	Cut Slope	Fill Slope	Cu. Yd. per 100′	Cu. Yd. per Mile	Cut Slope	Fill Slope	Cu. Yd. per 100′	Cu. Yd. per Mile
5°	9%	1½:1	1½:1	33	1750	1¼:1	1½:1	33	1750	1:1	1½:1	32	1700	¾:1	1½:1	32	1700	½:1	1¼:1	27	1430	¼:1	1:1	26	1380
10°	18%	1½:1	1½:1	67	3500	1¼:1	1½:1	64	3400	1:1	1½:1	60	3200	¾:1	1½:1	56	2950	½:1	1¼:1	41	2200	¼:1	1:1	38	2000
15°	27%	1½:1	1½:1	115	6200	1¼:1	1½:1	110	5800	1:1	1½:1	102	5400	¾:1	1½:1	94	5000	½:1	1¼:1	80	4200	¼:1	1:1	72	3800
20°	36%	1½:1	1½:1	240	12700	1¼:1	1½:1	210	11100	1:1	1½:1	185	9800	¾:1	1½:1	170	9000	½:1	1¼:1	128	6800	¼:1	1:1	107	5700
25°	47%	....	....	...	....	1¼:1	1½:1	365	19400	1:1	1½:1	292	15400	¾:1	1½:1	242	12800	½:1	1¼:1	185	9800	¼:1	1:1	150	7800
30°	58%	....	....	...	....	....	....	...	....	1:1	1½:1	563	29800	¾:1	1½:1	435	22900	½:1	1¼:1	278	14700	¼:1	1:1	195	10300
35°	70%	....	....	...	....	....	....	...	....	....	....	...	....	....	....	...	....	½:1	1¼:1	455	24100	¼:1	1:1	274	14500
40°	84%	....	....	...	....	....	....	...	....	....	....	...	....	....	....	...	....	....	....	...	....	¼:1	1:1	425	22500

As a general rule a retaining wall section should be used when the natural ground slope exceeds 30°, except for solid rock fill which can be used up to 40° slope.

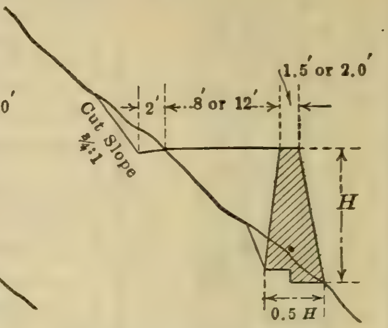
These balanced sections are computed and balanced on the basis that 1.2 cu. yd. of excavation will make 1 cu. yd. of fill. Where the cut slopes will stand at ½:1 or ¼:1 we have assumed that 1 cu. yd. of excavation will make 1 cu. yd. of fill allowing for rock waste that will probably occur.

Approximate Quantities Wall Section Minimum

Single-track Road, Sec. W-8
Double-track Road, Sec. W-12



TYPICAL SECTIONS
30° & 35° Slopes
Ditch Excavation Makes
Fill Back of Wall



TYPICAL SECTIONS
40 & 45 Cross Slopes
Borrow Fill Required

NOTE.—Rough rubble masonry walls to have outside face batter of 3″ to 1′ and a bottom width of ½ the height. The foundation to be carried to a firm strata.

Natural Ground Cross Slope	Approximate Quantities per 100′ of Road for W-8 Section				
	Wall Masonry	Ditch Excavation Used in Fill	Borrow Excavation for Balance of Fill	Wall Excavation Waste	Total Excavation
*30°	46 cu. yd.	55 cu. yd.	None	15 cu. yd.	70 cu. yd.
35°	55 " "	80 " "	None	20 " "	100 " "
40°	100 " "	30 " "	90 cu. yd.	35 " "	155 " "
45°	135 " "	45 " "	100 " "	45 " "	200 " "

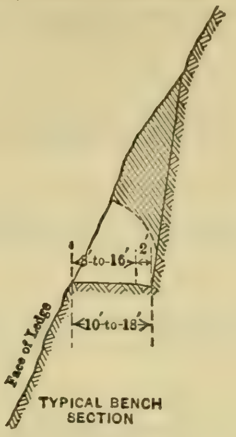
Table for Minimum Double Track Section W-12

Natural Ground Cross Slope	Approximate Quantities per 100′				
	Wall Masonry	Ditch Excavation Used in Fill	Borrow Excavation for Balance of Fill	Wall Excavation Waste	Total Excavation
*30°	65 cu. yd.	100 cu. yd.	None	15 cu. yd.	115 cu. yd.
35°	90 " "	140 " "	None	20 " "	160 " "
40°	180 " "	30 " "	200 cu. yd.	45 " "	275 " "
45°	250 " "	45 " "	250 " "	80 " "	375 " "

NOTE.—Above 45° ground slope use Rock Bench Sections, except in unusual cases.

* Retaining wall section on 30° cross slope is not usually economical.

Table of Approximate Quantities Road Benched Out of Rock



Using S-8, S-10, S-12, S-14, S-16

Natural Slope of Face of Rock Ledge	Cut Slope	Approximate Excavation in Cu. Yd. per 100' for Different Sections				
		*S-8	S-10	**S-12	S-14	S-16
50°	¼:1	350 cu yd	500 cu yd	660 cu yd	870 cu yd	1,100 cu yd
60°	¼:1	600 " "	850 " "	1,200 " "	1,550 " "	2,000 " "
70°	Vertical	560 " "	800 " "	1,050 " "	1,400 " "	1,800 " "
80°	Half Tunnel	460 " "	550 " "	680 " "		

* Minimum width single track in rock.
** Minimum width double track in rock.

Approximate Amounts of Embankment and Excavation for Different Center-line Cuts and Fills, Ground Surface Assumed Level

(See page 794.)

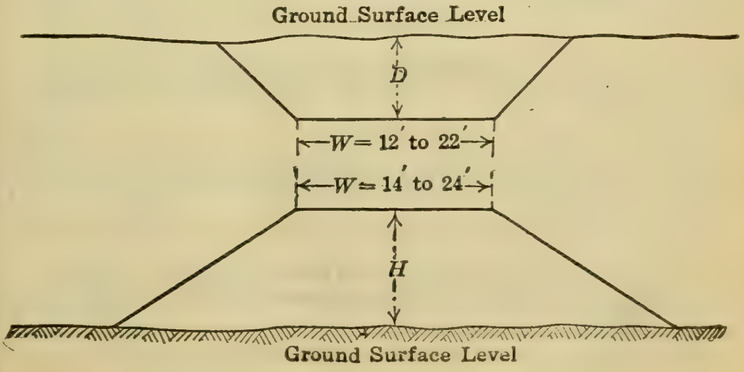


TABLE 129.—APPROXIMATE YARDAGE PER 100 FEET FOR CUT SECTIONS

Center Line Cut in Feet D	W = 12′		W = 14′		W = 16′		W = 18′		W = 20′		W = 22′	
	Cut Slope 1½:1	Cut Slope 1:1	Cut Slope 1½:1	Cut Slope 1:1	Cut Slope 1½:1	Cut Slope 1:1	Cut Slope 1½:1	Cut Slope 1:1	Cut Slope 1½:1	Cut Slope 1:1	Cut Slope 1½:1	Cut Slope 1:1
0.5	24	23	27	27	31	30	35	34	38	38	42	42
1.0	50	48	57	55	65	63	72	70	80	78	87	85
1.5	79	75	90	86	101	97	112	108	124	120	135	131
2.0	111	104	126	119	141	134	156	149	170	163	185	178
2.5	146	134	164	152	183	171	201	189	220	208	238	226
3.0	183	167	205	189	228	212	250	234	272	256	294	278
3.5	224	201	250	227	276	253	302	279	328	305	354	331
4.0	266	237	296	267	325	296	355	326	385	356	414	385
4.5	312	275	345	308	379	342	412	375	445	408	479	442
5.0	361	315	398	352	435	389	472	426	510	463	546	500
6.0	467	400	511	444	556	489	600	533	645	578	689	622
7.0	583	492	635	544	687	596	738	647	790	699	842	751
8.0	711	592	770	651	830	711	889	770	948	829	1007	888
9.0	850	699	916	766	982	832	1050	900	1116	966	1183	1033
10.0	1000	814	1074	888	1148	962	1222	1036	1296	1110	1370	1184
12.0	1333	1067	1422	1156	1511	1245	1600	1334	1689	1423	1778	1512
14.0	1711	1348	1815	1452	1919	1556	2023	1660	2127	1764	2231	1868
16.0	2133	1660	2251	1778	2369	1896	2488	2015	2607	2134	2726	2253
18.0	2600	2000	2733	2133	2866	2266	3000	2400	3133	2533	3266	2666
20.0	3111	2370	3259	2518	3407	2666	3555	2814	3703	2962	3852	3111

TABLE 129.—APPROXIMATE YARDAGE PER 100 FEET FOR FILL SECTIONS—*Continued*

Center Line Fill = H in Feet	W = 14′ Fill Slope 1½:1	W = 15′ Fill Slope 1½:1	W = 16′ Fill Slope 1½:1	W = 17′ Fill Slope 1½:1	W = 18′ Fill Slope 1½:1	W = 19′ Fill Slope 1½:1	W = 20′ Fill Slope 1½:1	W = 21′ Fill Slope 1½:1	W = 22′ Fill Slope 1½:1	W = 23′ Fill Slope 1½:1	W = 24′ Fill Slope 1½:1	W = 26′ Fill Slope 1½:1
0.5	27	29	31	33	35	37	38	40	42	44	46	50
1.0	57	61	65	69	72	76	80	84	87	91	95	102
1.5	90	95	101	106	112	118	124	129	135	140	146	157
2.0	126	134	141	149	156	164	170	178	185	193	200	215
2.5	164	173	183	192	201	210	220	229	238	247	256	275
3.0	205	216	228	239	250	261	272	283	294	305	316	339
3.5	250	263	276	289	302	315	328	341	354	367	380	406
4.0	296	310	325	340	355	360	385	400	414	429	444	474
4.5	345	362	379	396	412	429	445	462	479	496	513	546
5.0	398	416	435	453	472	490	510	528	546	564	582	620
6.0	511	533	556	578	600	622	645	667	689	711	733	778
7.0	635	661	687	712	738	764	790	816	842	868	894	945
8.0	770	800	830	860	889	919	948	978	1007	1037	1067	1126
9.0	916	949	982	1015	1050	1083	1116	1149	1183	1216	1250	1317
10.0	1074	1111	1148	1185	1222	1259	1296	1333	1370	1407	1444	1518
12.0	1422	1466	1511	1555	1600	1644	1689	1733	1778	1823	1867	1956
14.0	1815	1867	1919	1971	2023	2075	2127	2179	2231	2284	2336	2439
16.0	2251	2310	2369	2429	2488	2547	2607	2666	2726	2785	2844	2963
18.0	2733	2800	2866	2933	3000	3067	3133	3200	3266	3333	3400	3533
20.0	3259	3333	3407	3481	3555	3629	3703	3777	3852	3926	4000	4148

MISCELLANEOUS INFORMATION OF VALUE IN MAKING PRELIMINARY INVESTIGATIONS AND ESTIMATES

TABLE 130.—CONVERSION PER CENT OF GRADE TO DEGREES OF VERTICAL ANGLE

(For use in tracing grade with transit or Abney Level)

Per Cent.	Degrees	Per Cent.	Degrees
1	0° 35′	9	5° 09′
2	1° 09′	10	5° 43′
3	1° 43′	11	6° 17′
4	2° 18′	12	6° 51′
5	2° 52′	13	7° 24′
6	3° 26′	14	7° 58′
7	4° 00′	15	8° 32′
8	4° 35′		

TABLE 131.—TABLE OF ACRES PER STATION OF 100 FEET AND PER MILE FOR DIFFERENT WIDTHS OF CLEARING OR RIGHT OF WAY

Width of Strip	Acreage	
	Per 100′	Per Mile
30 ft	0.069 acres	3.636 acres
40 "	0.092 "	4.849 "
50 "	0.115 "	6.061 "
60 "	0.138 "	7.273 "
70 "	0.161 "	8.485 "
80 "	0.184 "	9.697 "
90 "	0.207 "	10.909 "
100 "	0.230 "	12.121 "

TABLE 132.—RANGE IN UNIT ESTIMATE PRICES (1918 COST CONDITIONS ROCKY MOUNTAIN DISTRICT)

Clearing and grubbing:

Sage brush	\$ 10–\$ 50 per mil
Light clearing	20– 60 per acr
Medium clearing	60– 150 per acr
Heavy clearing	150– 300 per acr

Excavation:

Common:

Machine turnpiking	\$ 0.15–\$ 0.25 per cu. yd.
Wheel scraper and machine finish	0.25– 0.35 per cu. yd.
Wagon haul and machine finish	0.40– 0.60 per cu. yd.
Side-hill plow, scraper, and machine	0.35– 0.75 per cu. yd.

TABLE 132—*Continued*

Disintegrated rock or dry, hard clay:	
Considerable hand work or shooting	0.75– 1.00 per cu. yd.
Solid rock:	
Blasting open cut, per cubic yard	0.80– 2.00 per cu. yd.
Tunnel work	4.00– 5.00 per cu. yd.
taining walls:	
Rough dry rubber masonry	1.00– 3.00 per cu. yd.
Mortar rubber	4.00– 8.00 per cu. yd.
ncrete	6.00–20.00 per cu. yd.
mber and lumber	30.00–80.00 per cu. yd.
rpenter work:	
Simple structures	$ 5.00–10.00 per M ft. B.M.
Truss framing, etc	10.00–20.00 per M ft. B.M.

BLE 133.—APPROXIMATE COST PER FOOT OF LENGTH, SMALL DRAINAGE STRUCTURES

Size of Opening	Kind of Structures				
	Vitrified Pipe	Corrugated Metal Pipe	* Cast Iron Pipe	** Concrete Boxes	Log Culverts
12″	$0.60	$1.25	$2.00		
15″ or 16″	0.90	1.50	2.90		
18″	1.10	1.80	3.40		
24″	2.00	2.75	5.50		
36″	3.75	4.00	....		
48″	....	6.50	....		
2′ × 2′	....	....	....	3.75	$1.50
2′ × 3′	....	....	....	4.80	1.70
3′ × 3′	....	....	....	5.40	2.30
3′ × 4′	....	....	....	6.00	2.80
4′ × 4′	....	....	....	6.75	3.00
4′ × 5′	....	....	....	8.00	3.60
5′ × 5′	....	....	....	8.70	4.00

* Based on $50 per ton in place.
** Based on $10 per cubic yard in place.

Culvert Data.—Local conditions must be considered in prices of aterials, haul, etc., for a close estimate.

Table 199 (p. 1080) gives weights of corrugated pipe.

Table 197 (p. 1079) gives weights of cast-iron pipe.

Quantities of concrete can be figured from standard designs ven in Chap. IV.

Timber in superstructures can be figured from standard designs Chap. IV.

The summarized data shown in Table 133 will, however, act as ough guide.

TABLE 134.—AMOUNTS OF MASONRY IN TWO ABUTMENTS AN FOUR WINGS FOR VARIOUS HEIGHTS OF ABUTMENT FOR SMALL-SPAN TIMBER BRIDGE SUPERSTRUCTURES WITH 16′ ROADWAY

(H = height from bottom of foundation to bridge seat)

H in Feet	Cubic Yards	
	Concrete	Masonry
6	24 cu. yd.	29 cu. yd.
7	32 " "	38 " "
8	40 " "	49 " "
9	52 " "	60 " "
10	62 " "	74 " "
12	90 " "	105 " "
14	133 " "	153 " "
16	180 " "	200 " "
18	230 " "	260 " "
20	295 " "	325 " "

Compiled from Plate 74, (p. 265).

TABLE 135.—APPROXIMATE AMOUNT OF TIMBER IN SMALL-SP STRINGER BRIDGE SUPERSTRUCTURES HAVING 16′ ROADWAY AND FIGURED TO CARRY A 20-TON LOAD

(Figured from Plate 79, p. 294)

Clear Span	Feet B. M.	Pounds Hardware
6 ft.	1000	70 pounds
8 "	1400	90 "
10 "	1700	110 "
14 "	2500	130 "
18 "	3300	150 "

NOTE.—For timber spans 30 to 50′, see Plates 81 and 82 (p 301 to 302).

Pile abutments can be figured from Plate 79, (p. 294).

Net Volume of Logs in Board Measure.—A convenient appro mate rule for computing the net number of feet, board measure, sawed timbers in logs is as follows:

$$\frac{\text{Diameter in inches} \times \text{radius in inches}}{12} = \text{Feet, board measu per foot of log.}$$

Example.

Suppose a log 10′ long, 12″ in diameter.

$$\frac{\text{Diameter} \times \text{radius}}{12} = \text{number of feet, board measure, per foot of log.}$$

$$\frac{12 \times 6}{12} = 6' \text{ B. M. per foot} \times 10' = 60' \text{ B. M.}$$

Steel Bridges.—The diagrams on page 763 taken from various sources will serve as a basis for rough estimates on longer-span steel highway bridges. They are figured for a live load of 100 lb. per square foot and presumably for a plank floor. They are of much lighter construction than called for on heavy-traffic roads where solid floors and a heavier loading are gaining favor.

These diagrams are useful as a basis of estimating dead loads of old bridges. The amounts of steel for modern bridges is given on pages 760 and 761.

Magnetic Declination.—The following isogonic charts give the approximate magnetic declination for states east and west of the Mississippi for Jan. 1, 1915. The yearly change is given. These charts will give a value close enough for preliminary investigation purposes. For meridian determination for location surveys, see Chap. XIII, Polaris and Solar Meridians.

Explanation of Plates pages 800 and 806 (Taken from U. S. Coast and Geodetic Chart)

The solid lines on these charts are lines of equal magnetic declination.

The dot and dash lines are lines of equal yearly rate of change in the magnetic declination.

The charts show the magnetic declination for Jan. 1, 1915.

Lines marked "East Declination" mean that the north end of the magnetic needle points east of true north.

Lines marked "West Declination" mean that the north end of the needle points west of true north.

For localities east of the line of no annual change the north end of the magnetic needle is moving west. For localities west of this line it is moving east at the rate shown by the lines of annual change. The location of the line of no annual change is shown on pages 804 to 806.

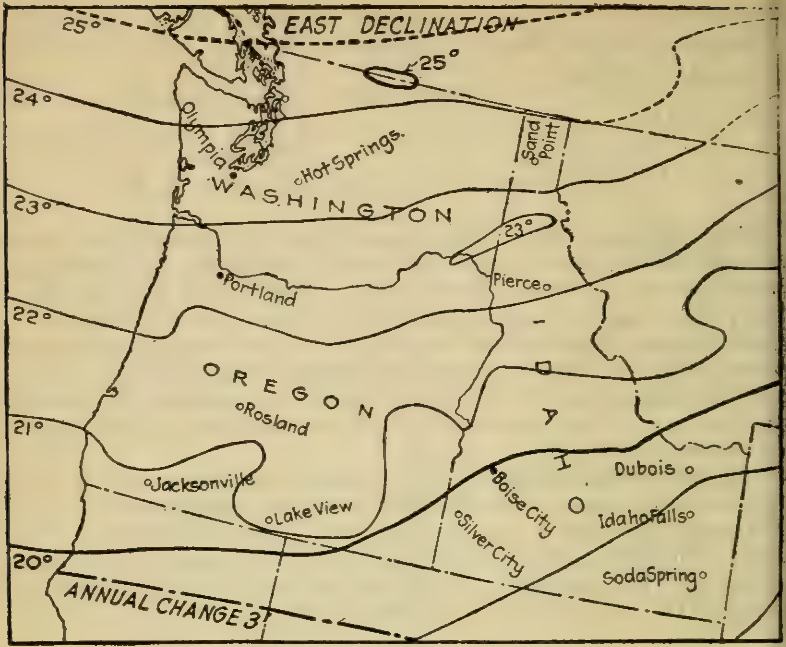


FIG. 266.—Magnetic declinations (1915).

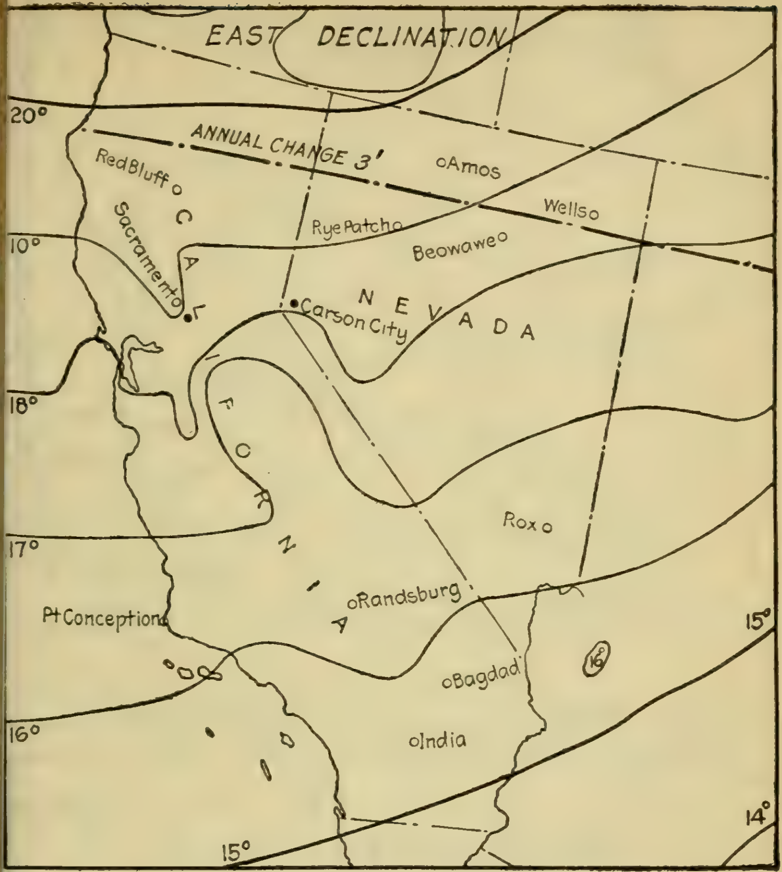
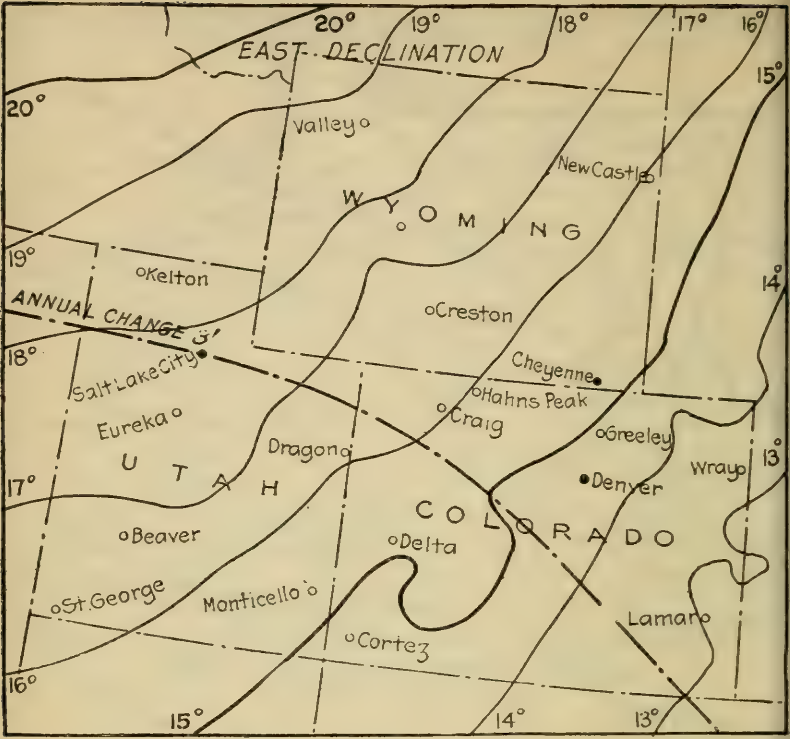


Fig. 266.—Magnetic declinations (1915).—(*Continued.*)



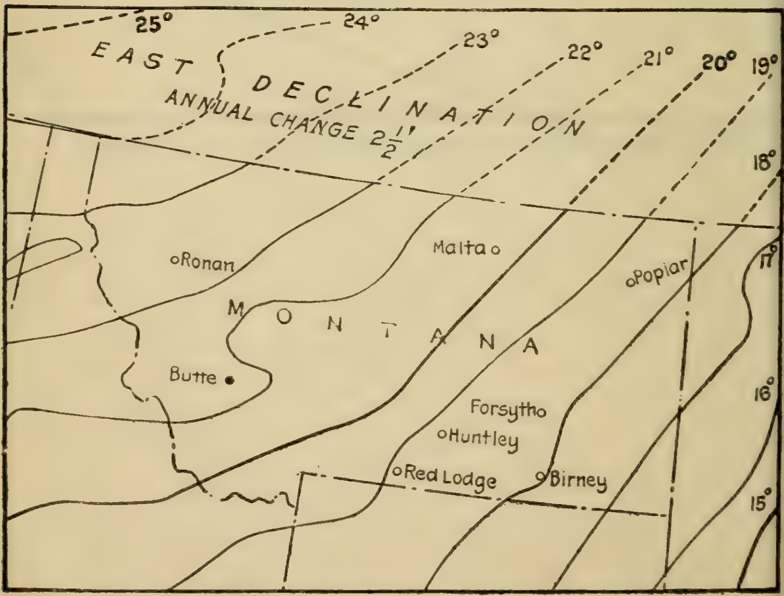
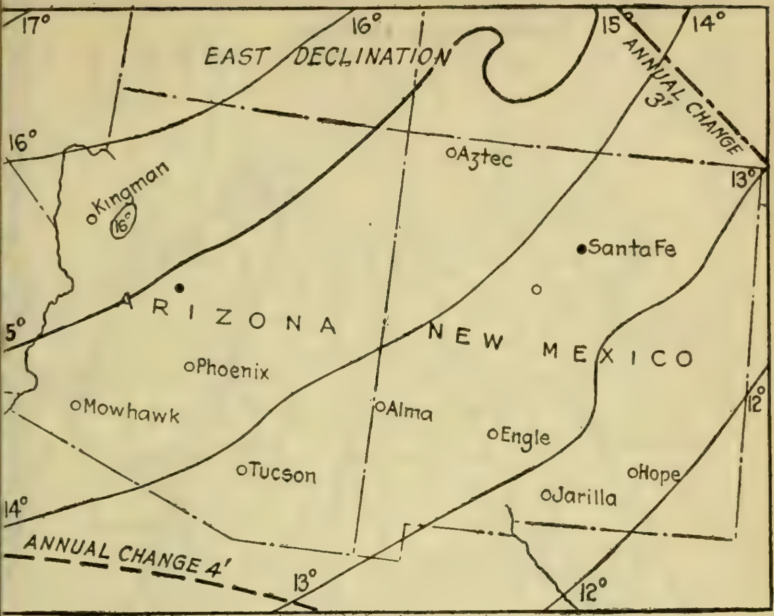


FIG. 266.—Magnetic declinations (1915).—(*Continued.*)



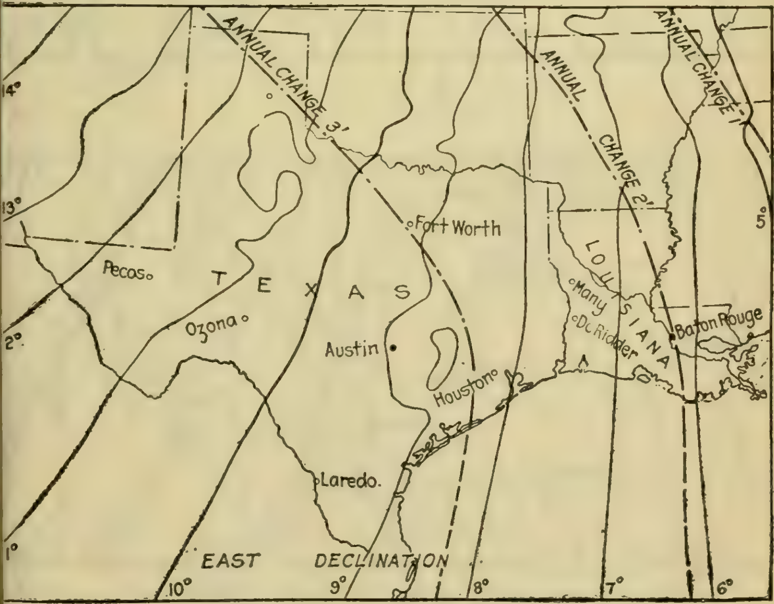
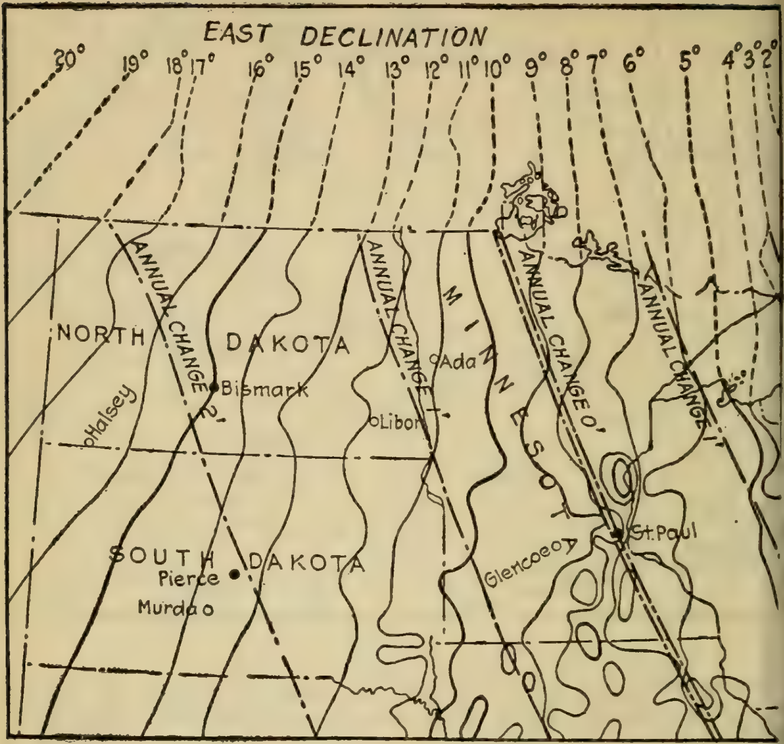


FIG. 266.—Magnetic declinations (1915).—(*Continued.*)



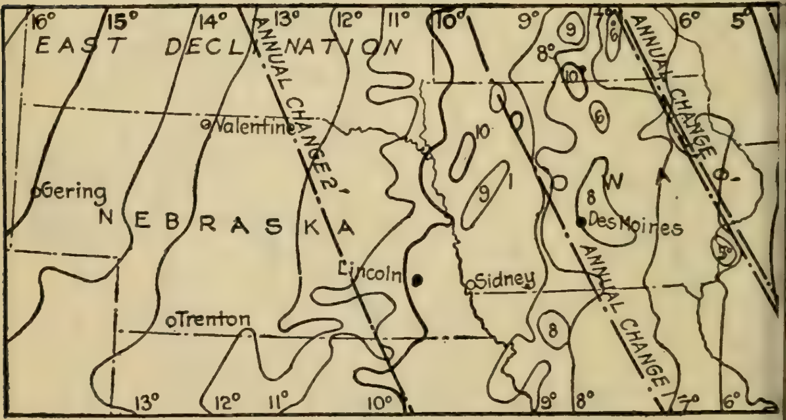


FIG. 266.—Magnetic declinations (1915).—(*Continued.*)

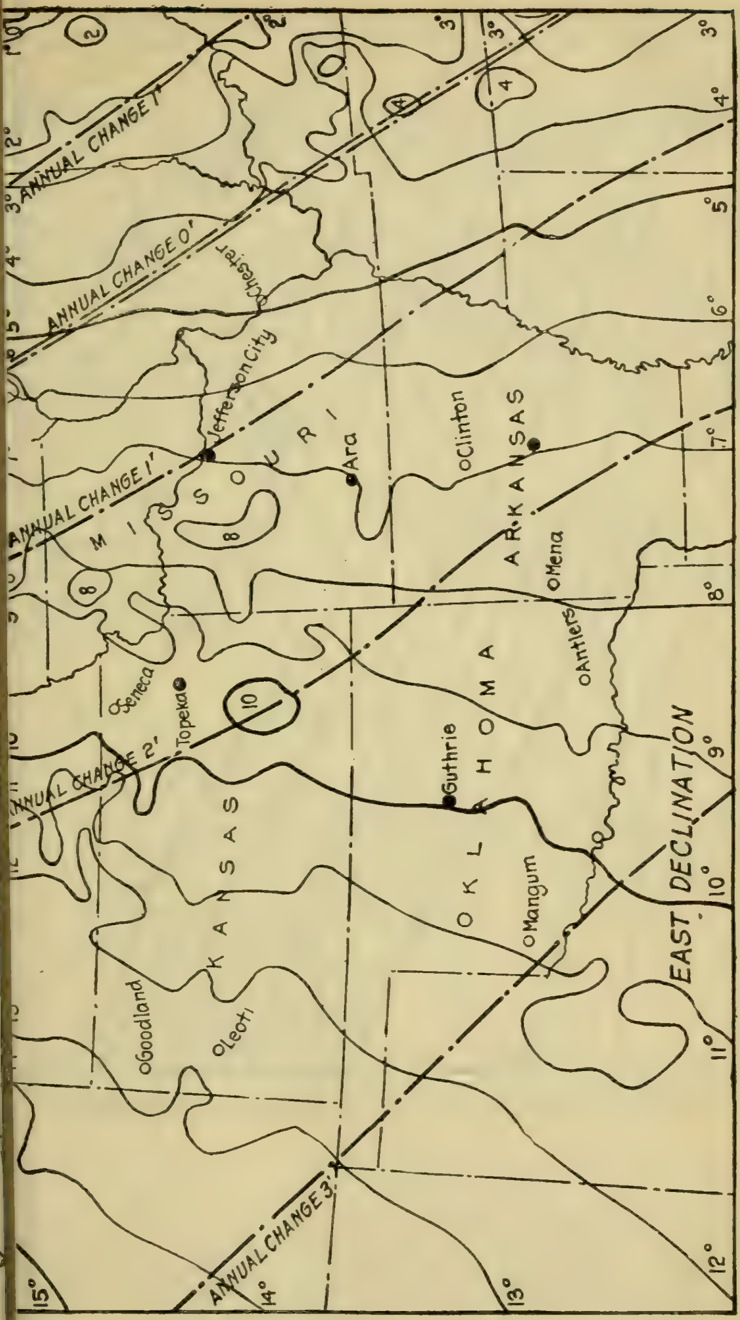


FIG. 266.—Magnetic declinations (1915).—(*Continued.*)

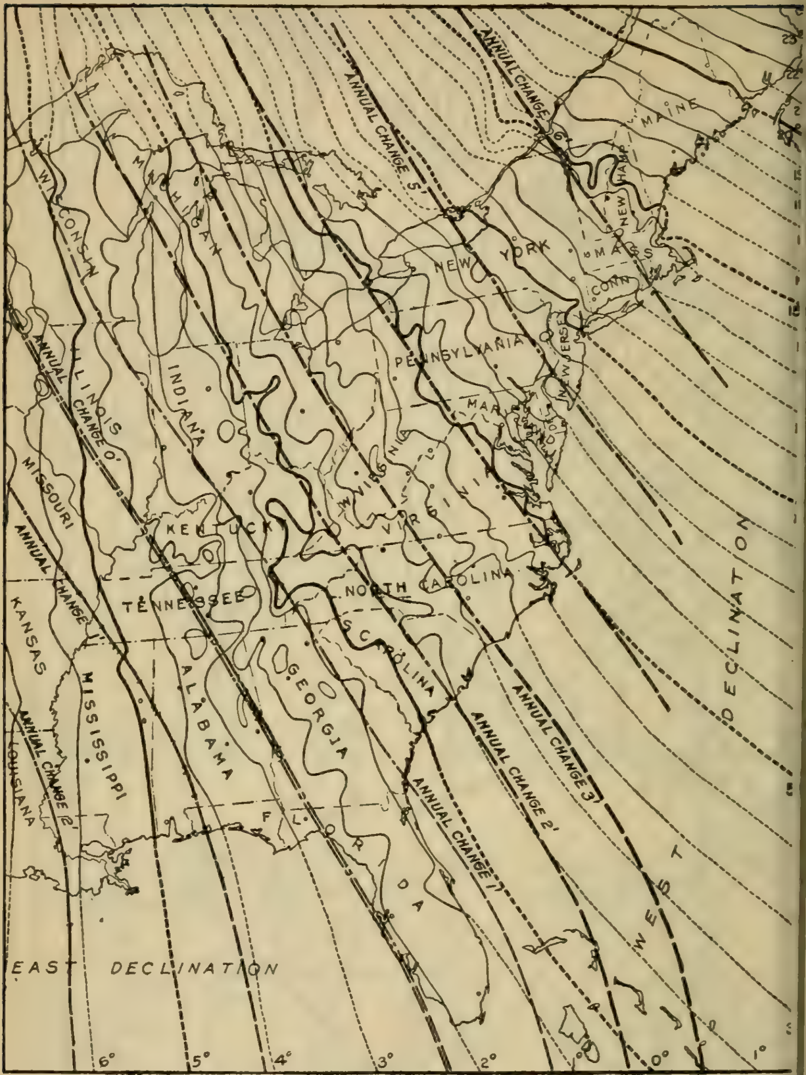


FIG. 266.—Magnetic declinations (1915).—(*Continued.*)

The following sample report shows a form in ordinary use for eliminary investigations, which covers the information required.

EPORT ON PRELIMINARY INVESTIGATION OF THE RED GAP–BIG BEAR RANCH HIGHWAY IN PATERSON AND GRANT COUNTIES, STATE OF ————, 1919

tate Commissioner of Highways,
Dear Sir:

"Complying with your request of May 10, a preliminary investigation of e proposed Red Gap--Big Bear Ranch Highway was made June 1 to 10.

"There is only one feasible route, via Clear River Ranch, Coal Basin, ray Horse Divide, See Creek, and Blackwater River, a total distance of miles. This route is free from snow 7 months in the year. A double-ck road from Red Gap to Coal Basin and a single-track road with turnouts d permanent drainage structures for the remaining distance will cost proximately $175,000.

"In case the entire project cannot be undertaken by one appropriation, recommend the following order of construction of the various sections own on the accompanying map (p. 268).

First in importance	G 4, G 5,
Second in importance	G 7,
Third in importance	G 6,
Fourth in importance	G 2, G 3,
Fifth in importance	G 1, P 1, P 2,
Sixth in importance	P 3, P 4,
Seventh in importance	P 5,

The report in detail follows.

Signed,
Field Engineer.

Table of Contents

"The field notes on which this report is based can be found in Field Book 3, Preliminary Investigation file.

1. Introduction

"It is proposed to build a new road over Stray Horse Divide connecting e valleys of the Clear and Blackwater Rivers and to improve the location, ade, and width of the existing roads in these valleys. The highway will end from Red Gap in Paterson County to Big Bear Ranch in Grant unty, a distance of approximately 30 miles. It will open up a valuable ming section on the upper Blackwater River and will afford more direct mmunication between these two counties.

2. Length in Counties and Benefits

"**Paterson County.**—Red Gap to Stray Horse Divide, 8 miles.

"**Grant County.**—Big Bear Ranch to Stray Horse Divide, 22 miles.

"Paterson County will be benefited by a better and quicker connectic with communities to the south and by the large amount of tourist trav which will undoubtedly use this road.

"Grant County will gain a more direct route to an isolated portion of i territory and will help the development of a promising farming section the upper Blackwater River.

"While none of this road lies in Socorro County, this county will be mo directly benefited than Paterson County, as the natural outlet for tra and produce up the Blackwater lies toward Lochiel.

3. Methods of Investigation

"**Field Work.**—The entire line was covered twice on foot June 1 to noting the controlling points (aneroid elevations), the general classificati of materials, the side-hill slopes, and reasonable ruling grades.

"**Office Work.**—The office estimate is based on paced distances check by Forest Service maps and maps of the Clear River R. R.

"The excavation per running foot on side-hill work is based on cross-slo taken with an Abney level at frequent intervals and is figured on the princi of balanced side-hill sections, adding different percentages for inequalit in profile.

"The classification of excavation is made roughly from notes on the gene character of the formations.

"The drainage is approximated for the smaller structures. The lar bridges are noted in more detail.

"Estimates have been prepared for various widths of roadway.

4. Present Condition of Roads and Trails

"**Paterson County** (Red Gap to Stray Horse Divide).—There is a f wagon road from Red Gap to Clear River Ranch, about 2 miles south; a sc but poor wagon road from this point to Coal Basin; a fair road from C Basin to Stray Horse Station; and a well-marked but steep trail from t point to the top of Stray Horse Divide.

"**Grant County** (Stray Horse Divide to Big Bear Ranch).—There is easy trail from Stray Horse Divide to Blackwater River, approximat 8 miles; a very poor wagon road down Blackwater River from See Creek Adams Ranch, approximately 9 miles. The road between these poi crosses the river eight or ten times by fords and cannot be used at all if water is much above low stage. Under the best conditions a good te cannot haul over 1 ton.

"From Adams Ranch to Big Bear Ranch (about 5 miles) the road is p and dangerous in many places. It is so steep that 1½ tons is about maximum load for an exceptionally good team under the best conditions.

"While this project ends at Big Bear Ranch it should be noted that if road from this point to Lochiel in Socorro County, the nearest railroad poi is not improved the value of this project will be practically lost. The pr ent road to Lochiel is dangerous, limits a team load to about 1½ tons, a will be an expensive road to improve. I estimate roughly that $40,000 be required to put it into reasonably good shape.

5. General Topography

"**Paterson County** (Red Gap to Stray Horse Divide. See photographs 1 10).—From Red Gap south for about 2½ miles the topography is abru Red sandstone and conglomerate cliffs and dykes hold the road locat closely to the Clear River. From this point to about ½ mile south of C Basin occasional cliffs occur, but a careful location will avoid them and it be possible to gain some elevation along the sides of the valley. From point to Stray Horse Divide and for a couple of miles south of the pass th are no cliffs, and while the slopes are steep, averaging 25 to 40°, the locat can be placed at any desired elevation. This strip of country is fortunat favorable to location.

"**Grant County** (See photographs 11 to 30).—From Stray Horse Divide to hompson's Ranch the formation is favorable for location on any desired ade. Few rock outcrops occur. The slopes average 20 to 25°.

"From Thompson's Ranch down See Creek is an ideal road location. No lid rock, very little loose rock, easy water grade. The side slopes average ° for one-half the distance and 20° for the balance of the way.

"From the junction of See Creek and Blackwater River down the east de of the Valley to Buck Creek the location is easy on a side hill, averaging ° side slope. There are no rock outcrops and very little loose rock. An sy grade can be obtained.

"From Buck Creek to Spring Creek along the side hill on the east side of ackwater River the following conditions prevail: Average side-hill slope 30°; mile of rock-ledge slope of face approximately 60°. Expensive work nnot well be avoided, but an easy grade can be obtained.

"From Spring Creek to Adams' Ranch the formation on the east side of the lley is favorable for location at some distance away from the river. A ling grade of 5% can be obtained at the worst places and ordinarily the ade is light. Benches and side-hill slopes are easy, averaging 15° for one-lf the distance and 30° for the remainder.

"From Adams' Ranch to Big Bear Ranch the best location lies on the st side of the valley. Difficult country is encountered—heavy scrub-oak ush, many large boulders, and considerable solid rock. The river changes channel frequently and any permanent road location must be placed yond its reach, necessitating expensive work.

"The natural soil from Big Bear Ranch to Adams' Ranch is very slippery ien wet. To get a good safe road Creek Gravel should be used as surfacing. nless the roadbed is sloped toward the hill (one-way crown) any of this cation will be dangerous in wet weather. This same condition applies in less marked degree all the way up Blackwater River to See Creek.

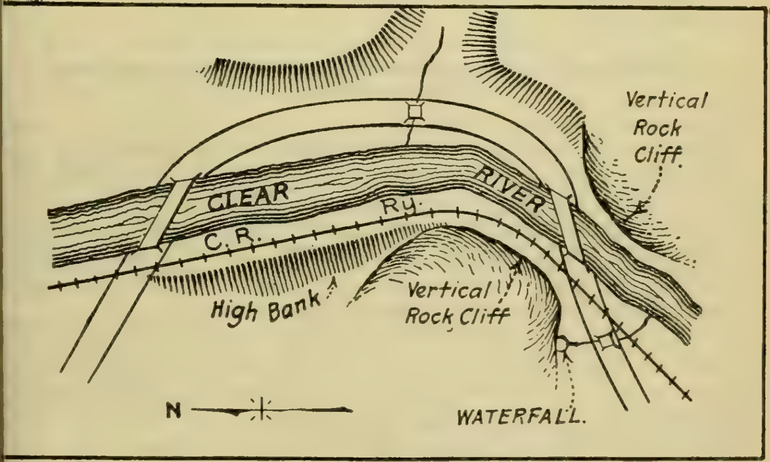


FIG. 267.

6. Proposed General Route

"**Paterson County.**—From Red Gap, the proposed road follows the esent road, with some modifications to avoid unnecessary rise and fall, to first crossing of the Clear River about 1¾ miles south of Red Gap. om this point to the mouth of the Canyon, about ¼ mile, the location is en to argument. The existing road crossed the river twice (see sketch). th of these bridges were wrecked by the flood of 1918 and temporarily the vel is using the railroad track between these points.

"With the permission of the railroad it would be possible to widen out cut on the west side of the track and tunnel or half tunnel for about ′ around the rock bluff point, eliminating the two bridges and two railroad

crossings. On the other hand, the road would be very close to the track fo ¼ mile and would in my opinion be more dangerous for horse traffic than th old location requiring two bridges. The bridge location is recommended

"From the mouth of the gorge the road will follow approximately th location of the present highway to the top of Canyon Hill and thence on new location along the west side of the Clear River Valley to Stray Hors Divide.

"**Grant County.**—Beginning at the county line at Stray Horse Divide new location will follow down the north side of See Creek to a point abou 2½ miles southwest of Thompson's Ranch and thence along the south an east side of See Creek and Blackwater River to Adams' Ranch. At Adams Ranch the road will cross to the west side of the valley and remain on thi side to Big Bear Ranch, the end of the proposed improvement varying some what from the location of the present road to better short sharp grades an to avoid creek flood areas.

7. Controlling Points (Aneroid Elevations)

Paterson County:	
Stray Horse Divide	9200
Bench between cliffs at Coal Basin	8200
Top of Canyon Hill	8100
Bottom of Canyon Hill	7930
Red Gap	7800
Grant County:	
Stray Horse Divide	9200
Thompson's Ranch	7900
2½ miles southwest of Thompson's (see Creek Crossing)	7500
Bench between cliffs between Buck and Spring Creek	715c
Adams Ranch	678c
Big Bear Ranch	660c

8. Description of Location Problems between Controlling Points
Paterson County

"**Stray Horse Divide to Coal Basin.**—The difference in elevation of the two points is approximately 1000′. The direct distance is about 1½ mile In order to get a good grade and come somewhere near Coal Basin, whic is probably desirable, it will be necessary to run south from Stray Hor Divide and then turn north. In this way any required ruling grade can b obtained and the length of road will depend entirely on the grade selecte The switchback can be made without too great cost by a careful locatio I recommend a 5% grade with a length of 4 miles. The road, in genera will follow the contours. Two pronounced gulleys are crossed which can b bridged or filled as determined on the location survey.

"By the use of a 6 to 7% grade it is possible to run direct from Stray Hor Divide to the top of Canyon Hill. This solution should be carefully invest gated, but does not seem to be as good as the 5% location, as the topograph is not as favorable for location and, while it is shorter, the lighter grade is t be preferred and the extra length of road south of the divide will be utilize in the future as a part of the road to Stone Quarry.

"**Coal Basin to Top of Canyon Hill.**—Approximate length 1¾ mile Along contour of steep side hill for approximately ¾ mile and then alor bench cut up by small swales and knolls. No special features. Grade ar convenient to fit topography. No grade problem on this section. Excava tion largely earth and loose rock. One 20′ span bridge required.

"**Top of Canyon Hill to Bottom of Canyon Hill at Mouth of Gorge.**—Appro imate length 0.6 mile. Along side of Canyon following present highwa closely. Largely a question of equalizing grade by cut and fill. From ane oid elevations and Abney level, I judge that a 6% grade can be obtaine Certainly, a 7% can be built. This section of the road will be expensi and will govern the ruling grade from Red Gap to Stray Horse Divide. Th excavation will be approximately 50% solid rock. One 20′ span bridge w be required.

"**Mouth of Gorge (at Bottom of Hill) to Red Gap.**—Approximate lengt 2 miles. From mouth of gorge ¼ mile south to wagon road on the west si of the river the location is the most expensive of the entire project. Th strip will require either two bridges or heavy rock work, as previously di

ussed. The bridges are recommended. From this point to Red Gap there re no difficult problems, as the road will follow, in general, the present location and can be cheaply built. Another bridge at Red Gap will better the ocation and increase the convenience of the road.

Grant County

"**Stray Horse Divide to Thompson's Ranch.**—The difference in elevation s approximately 1300′. It is desirable to get down to a natural bench at Thompson's ranch. The length of road between these points will depend n the ruling grade selected. As it is a long climb, I recommend 5% with a ength of 5 miles, which can be obtained with one switchback turn. The ountry is favorable for location. Excavation is largely earth and some oose rock.

"**Thompson's Ranch to See Creek Crossing.**—Approximate length 2¼ niles. Ideal road location on bench. Easy grade. Excavation practically ll earth. Plow and machine scraper work. No grade problem. One 20′ pan bridge required.

"**See Creek Crossing to Buck Creek.**—Easy side-hill location except or ½ mile of rock ledge near Buck Creek. The location should keep upon he side hill to avoid abrupt river banks and slides due to freshet scour.

"**Buck Creek to Adams' Ranch.**—Easy sidehill and bench location. No difficulty in obtaining grades less than the maximum. Excavation arth and loose rock.

"**Adams' Ranch to Big Bear Ranch.**—Location problem one of protecting oad from river floods, also avoiding ledge and large boulder rock work. No hard grade problem. Excavation 50% loose rock, boulders, and solid edge.

9. General Recommendations and Costs

"The cost of construction under present conditions is uncertain. The rices used in the following detail estimates should be carefully noted in onsidering the possibility of cheapening the work by the use of convict abor. The costs used are for contract work and may vary greatly in a short ime.

"I recommend for this project a double-track side-hill section (S–14′) rom Big Bear Ranch to Coal Creek; a single-track side-hill section (S–10) ith turnouts from Coal Creek up to Blackwater River, See Creek over the Divide, and down to the top of Canyon Hill in Paterson County. A double-rack road from this point to Red Gap. Permanent culverts and bridges. Ruling grades of short 7% and long 5%. Alignment limited, as a rule, to a ninimum curvature of 100′ radius with a few 40′ radii at exceptionally bad laces.

"The cost of this type of road is estimated at approximately $175,000, ivided as follows:

learing and excavation	$108,000
ermanent culverts	20,000
ermanent bridges over 10′ span	35,000
ngineering	12,000
Total	$175,000

"If it is not possible to construct the entire project by one appropriation, would be well worth while to build from Big Bear Ranch to See Creek at nce to open up the new farming section on the Upper Blackwater. The ost of this portion of the road would be about $70,000.

"For details and various combinations of design see the following estimates y sections.

10. Detail Estimates

"**Classification of Materials.**—The classification of excavation cannot e accurately made; it is based on the following assumptions:

"Where the road is located on a bench near the bottom of a slope which ppears to be slide or wash formation and no rock outcrops are visible, the xcavation is classed as 99% common and 1% rock.

"Where the location is on a steep main mountain slope of 25 to 35° covered with loose rock but no solid rock outcrops are visible, the assumptior has been that solid rock will be encountered 6′ back of the slope surface.

"Where occasional outcrops occur rock is assumed 4′ back of the surface

"Any extended rock ledge has been noted.

UNIT PRICES

Clearing:	
Sage brush	$ 30 per mil
Light brush and trees	30 per acr
Medium brush and trees	100 per acr
Excavation:	
Solid rock	$1.00–$1.50 per cubic yar
Tunnel rock	4.00 per cubic yar
Common excavation:	
Turnpike in earth	0.18 per cubic yar
Side-hill plow and scraper	0.30– 0.40 per cubic yar
Wagon haul and scraper	0.40 per cubic yar
Concrete	12.00 per cubic yar
18″ corrugated pipe	2.00 per foot
Rough rubber retaining wall	2.00 per cubic yar

"**Division into Sections.**—For purpose of estimating, the road is divide into the following sections:

PATERSON COUNTY

	Miles
Sec. P-1 Stray Horse Divide to Coal Basin	4.0
Sec. P-2 Coal Basin to top of Canyon Hill	1.8
*Sec. P-3 Canyon Hill	0.6
*Sec. P-4 Canyon Hill to Clear River Ranch	0.2
*Sec. P-5 Clear River Ranch to Red Gap	1.7
Total Paterson County	8.4

GRANT COUNTY

Sec. G-1 Stray Horse to Thompson's Ranch	5.0
Sec. G-2 Thompson's Ranch to See Creek Crossing	2.5
Sec. G-3 See Creek Crossing to Blackwater River	1.0
*Sec. G-4 See Creek and Blackwater to Buck Creek	2.5
*Sec. G-5 Buck to Spring Creek	2.0
*Sec. G-6 Spring Creek to Adams' Ranch	4.5
*Sec. G-7 Adams' Ranch to Big Bear Ranch	4.3
Total Grant County	21.8

"NOTE.—See map for location of these sections. The sections marke with a * have a poor wagon road at present, which, however, can be usec Sections having no star require new construction to permit wagon traffic.

"**Estimate of Sections. Sec. P-1.**—(Length 4.0 miles.)

"**Clearing.**—Six acres per mile for 3 miles = 18 acres at $100 = $1800.

"**Drainage.**—Say 10 culverts per mile for 4 miles at $700 per mile = $280

"**Excavation for Double-track Road.**—Side-hill slope averages 27 Excavation per mile for balanced section S = 14 equals approximatel 13,000 cu. yd. for a 1:1 cut slope, which is considered safe for this materia Add 25% for inequalities of profile, giving 16,200 cu. yd. per mile, or 55,00 cu. yd. for 4 miles. It is estimated that 20% of this, or 11,000 cu. yd., rock excavation and the balance, 44,000 cu. yd., is common.

44,000 cu. yd. common at $0.40	$17,60
11,000 cu. yd. rock at 1.20	13,20
Total excavation	$30,80

Excavation for single-track road S–10:

Excavation per mile balanced section	7,400 cu. yd.
Add for profile 25%	1,850 cu. yd
	9,200 cu. yd.

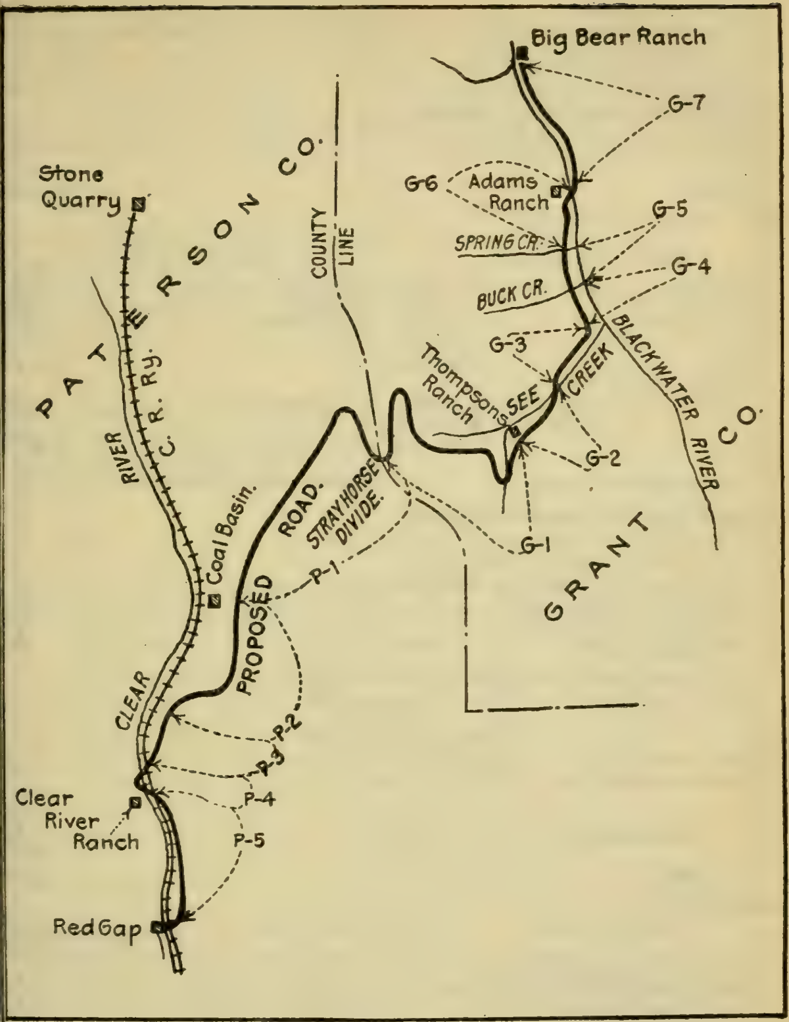

Big Bear Ranch
G-7
Stone Quarry
PATERSON CO.
COUNTY LINE
G-6
Adams Ranch
G-5
SPRING CR.
G-4
BUCK CR.
G-3
BLACKWATER RIVER
Thompsons Ranch
SEE CREEK
C. R. Ry.
RIVER
G-2
CO.
STRAYHORSE DIVIDE
ROAD.
Coal Basin
P-1
G-1
GRANT
PROPOSED
CLEAR
P-2
P-3
Clear River Ranch
P-4
P-5
Red Gap

Fig. 268.

Assume 10% rock	900 cu. yd. per mile
Assume common excavation	8,300 cu. yd. per mile

Cost of excavation for 4 miles:

3,600 cu. yd. rock at $1.50	$ 5,400
33,000 cu. yd. common at $0.33	11,000
Add for turnouts, five to the mile:	
500 cu. yd. rock at $1.20	600
1,500 cu. yd. common at $0.40	600
Total	$17,60

Summary of cost, Sec. P-1:

Double-track Road		Single-track Road	
Clearing	$ 1,800	Clearing	$ 1,80
Drainage	2,800	Drainage	2,80
Excavation	30,800	Excavation	17,60
	$35,400		$22,20
Contingencies, wall, etc.	2,600	Contingencies	1,80
	$38,000		$24,00
Equals $9,500 per mile		Equals $6,000 per mile	

Estimate Sec. P-2 (length 1.8 miles):

0.8 mile similar to Sec. P-1
1.0 miles average side slope 15°

Estimate of the easy mile (side slope 15°)

Clearing 6 acres at $50		$30
Drainage (ordinary)		50
20′ span bridge		80
Excavation (see S-14)	3,300 cu. yd. per mile	
Add for profile 25%	800 cu. yd. per mile	
	4,100 cu. yd. per mile	
Rock excavation	100 cu. yd. at $1.50	$ 15
Common excavation	4,000 cu. yd. at 0.30	1,20
		$2,95
Contingencies		15
Total		$3,1

Summary P-2:

	Double Track		Part Single an Part Double
0.8 mile similar to P-1			
at $9,500 per mile =	$7,600		
at $6,000 per mile =			$4,8
1.0 miles as per estimate above	3,100		3,1
	$10,700		$7,9
Say	11,000	Say	8,0

Estimate Sec. P-3 (length 0.6 mile). Double-track road based on hand-level profile:

Clearing 3 acres at $100	$ 3
3,000 cu. yd. common at $0.40	1,2
3,000 cu. yd. rock at $1.25	3,7
Ordinary drainage	5
1 20′ span bridge	8
	$6,5
Contingencies	1
Total	$6,7

stimate Sec. P-4 (length 0.25 mile):

stimate 1, based on location requiring two bridges over the Clear River.

Clearing	$ 20
1,000 cu. yd. common excavation at $0.40	400
200 cu. yd. rock at $1.50	300
400 cu. yd. rip-rap at $1.00	400
2 (80′ span solid-floor steel-truss bridges)	16,000
1 (20′ span concrete bridge)	800
	$17,920
Say	18,000

stimate 2, based on half tunnel west of track.

Clearing	$ 30
5,000 cu. yd. of common exc. at $0.40	2,000
4,500 cu. yd. rock tunnel work at $4.00	18,000
Stone wall between track and road	900
	$20,930
Say	$21,000

stimate Sec. P-5 (length 1.75 miles). Double-track road

pproximately same cost per mile as Sec. P-2 on the easy mile:

1.75 miles at $3,100 per mile	$ 5,425
Possible bridge at Rip Gap	8,000
	$13,425
Say	14,000

Summary of Costs, Paterson County

Section	Double track	Single track with turnouts
P-1	$38,000	$24,000
P-2	$11,000	8,000
P-3[1]	7,000	
P-4[1]	18,000	
P-5[1]	14,000	
	$88,000	
Engineering	$ 4,000	
Total appropriation	$92,000	

[1] Sections have usable wagon road at present.

"Estimated total cost for double-track road, Secs. P-3, P-4, and P-5, nd single-track road to the divide, Secs. P-1 and P-2, is $75,000.

"Estimated cost of cheap single-track road connecting present road to the ivide, Secs. P-1 and P-2, with temporary drainage structures and 6% ruling rade instead of 5%, $25,000.

Cost Estimate, Grant County

"In a similar manner detail estimates are made for the sections in Grant ounty, as summarized below. These estimates can be found in computa-on file F-32. They are not included in this report, as they are bulky.

SUMMARY OF COSTS, GRANT COUNTY

Section	Double track (S–14)	Single track (S–10) with turnouts (S–14)
G-1	$ 32,000	$ 22,000
G-2	33,000	3,000
G-3	5,000	3,000
G-4	10,000	7,000
G-5	20,000	12,000
G-6	26,000	20,000
G-7	36,000	25,000
	$132,300	$ 92,000
Engineering.........	7,700	8,000
Appropriation.......	$140,000	$100,000

TOTAL SUMMARY OF RECOMMENDED CONSTRUCTION

Paterson County....................................	$ 75,00c
Grant County.......................................	100,00c
Total..	$175,00(

RECONNAISSANCE SURVEYS

The methods described for ordinary investigations can be use for most cases, but for heavily wooded country or extremely difficu and rough topography a more careful survey is desirable.

Methods.—For open barren country the transit stadia method preferred by the author, using magnetic bearings, stadia distanc vertical angle profile and cross-slopes, and ordinary notebo sketches and recording. The map is plotted up on a scale 10c to the inch and the profile 100′ to the inch. The line is marked the field by tall stakes or lathes with a strip of cloth attached.

Work of this kind can be done by two men with very simp equipment. In remote regions a third man to move and care f camp equipment is required (see Chap. XIII).

Engineering Equipment.

Light mountain transit with stadia and verticle circle.
Light stadia rod, 8 to 10′ long.
Camera.
Notebooks, maps, etc.
100′ steel tape.
2 aneroid barometers.

For heavily wooded country the U. S. Geological methods are t cheapest and most satisfactory, using a light 15″ sketch plane tal and tripod oriented with a magnetic needle; 6″ gun sight alidac 500′ linen tape coated with paraffin for distance. Aneroid int mediate elevations checked by flying lines of spirit levels or stac levels along trails.

The main advantage of this method is that it requires no cuttir as direction is obtained by sighting by ear to a yell or whistle. also gives a complete contour map of all the territory that the ro can possibly traverse and makes it possible to lay out a better fir

ocation then any amount of scouting where the engineer depends n his memory and sense of direction for his final location. The rojected line is then followed with a rough plane table traverse, lopes, etc., taken, and the estimate made.

Work of this kind can be done by two men with very simple equipment for a cost ranging from \$10 to \$30 per square mile mapped. convenient scale to work on is 2000′ to the inch and a contour nterval ranging from 10 to 50′.

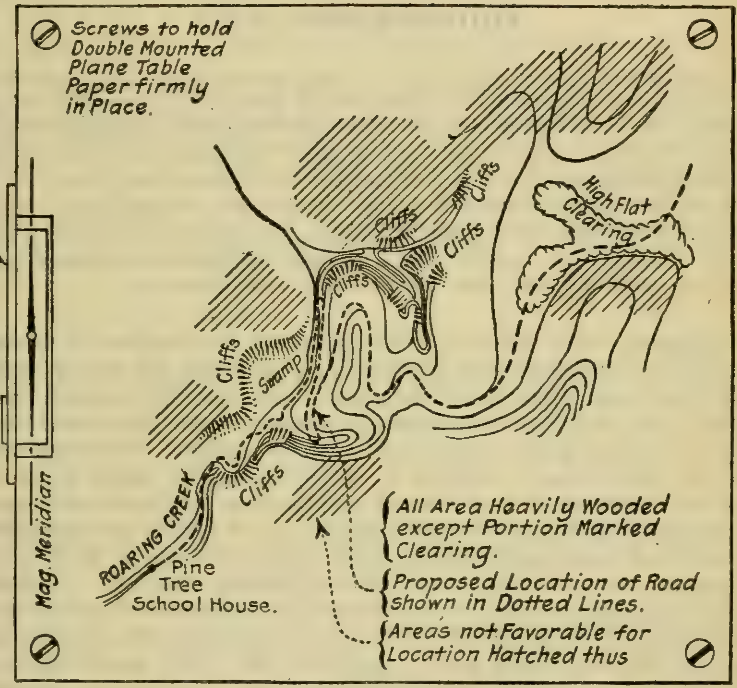


FIG. 269.

A third man to move and care for camp is desirable.

The engineering equipment required is:

15″ plane table with tripod.
500′ linen tape.
6″ gun sight alidade in leather case.
100 steel tape.
Plane table map paper.
2 aneroid barometers.
Light mountain transit with stadia (for flying levels).
Stadia rod.

Conclusion.—It should be borne in mind that if engineering is o be of value it must be thorough and that new locations will often x roads for generations.

There should be no hesitation in spending whatever is needed, even if it seems all out of proportion to the cost of the actual construction work to be performed within a year or so. Government programs carry out this principle and they are often criticized for high engineering cost, but is well worth while looking to the future.

The engineering program must be complete or it might just as well be discarded entirely

PHOTOGRAPHIC DATA

Editor's Note.—Photographs are often as important as survey notes particularly on reconnaissance work and the failure of a negative is comparable to the loss of field notes. The following data have been inserted to help the inexperienced photographer reduce his percentage of failures. A green hand is puzzled chiefly by diaphram opening and time of exposure and does not understand the effect of latitude, altitude, time of year, light, etc., on the problem. The following simple notes have been prepared by a man who has taken engineering photographs all over the world and should be helpful There are a number of very excellent exposure charts and mechanical sensitized paper exposure meters on the market which consider all these points in more detail than can be given in a book of this character.

General.—The following discussion of the subject of photography in connection with engineering operations has been prepared with the idea of giving to the engineer the foundations and principles upon which he may make exposures in the field under most all conditions, and secure fairly uniform results. The engineer is in the day's work, required to make exposures under some very adverse conditions, and it is not rare that the exposure most needed or the most important point along the line of survey or construction is reached when weather and light conditions are at their worst In many cases the results are failures, poor, or only fair. This fact under the ordinary procedure of having the film developed after the point has been passed, or the survey completed, is discovered weeks or months afterward, and a return to the point would either be expensive—so much so as to make it prohibitive—or impossible on account of adverse weather conditions.

Views on preliminary surveys are of more importance and should receive corresponding attention. Views on construction and location are important, but the opportunities for making successful exposures on location and construction are many. This is due to the fact that the engineer is located longer at one camp on location than on preliminary, while on construction he is constantly on the job.

It is urged that all work be done in the field at the time of making the exposures on preliminary investigations or reconnaissance surveys in order that failures may be discovered and additional exposures made which will supply the omissions, and assure a continuity of views. By so doing the finished view may then and there be properly identified and notations made as to its value in connection with the surveyed line, and the subsequent report and estimate With this end in view the following equipment is suggested.

Equipment.—1. Camera with good stout leather case and tripod.

2. Tank developing outfit complete.

3. Films, chemicals, and sufficient paper of photograph length of the line.

This outfit has been used for a number of years by men who have had a wide experience, and it has been found to be a convenient and complete camp kit to care for the picture end of a survey properly.

Roughly the films should be estimated at three exposures to the mile of line.

Camera.—The best-sized camera, that is, the one which produces the largest picture in proportion to the bulk of outfit and cost of operation, is the $4\frac{1}{4}$ by $6\frac{1}{2}''$ film camera—Eastman 4A. Cameras having smaller dimensions produce views so small as to be of little value from an engineering standpoint, while the outfit necessary to carry on development is practically the same in size and weight as that required for the camera above mentioned. Enlargements may be made, but this is an additional expense and delay. What is required is speed and accuracy.

This sized film when properly masked will give a picture $4\frac{1}{8}$ by $5\frac{3}{8}''$ exclusive of legend. If the roll is cut so as to leave the unexposed portions between the exposures, on the bottom of vertical views, or the left-hand end of horizontal views, space is left for filing number and legend. This information is put on the face of the film with india ink as soon as it is dry and is a clear but concise statement of (*a*) station from which the view was taken, (*b*) direction of the camera, (*c*) general description of features shown, or purpose for which taken, and (*d*) index number by which the same may be identified. This information is obtained from the exposure record which is made and kept at the time of the exposure and regarding which description is given on page 825.

Autographic backed cameras are in use but are not specially desirable unless the films are to be developed by some other person at a later date. The writing that may be done, while specific, is generally so large as to take up all the spa ce between the exposures which should be devoted to more detail. If used it is better to record merely the roll and exposure number, as R 23-2, and depend on the exposure record for detail data.

Lens.—The camera should be equipped with a standard lens of known value. In the matter of lenses nothing empirical may be said. Generally, however, the regular B. & L. f 16 rectilinear lens gives excellent results. As speed is not essential, the higher-priced rapid lenses are not necessary, and the investment of money in such a refinement which the work in hand does not call for is a luxury to say the least. Given a well-made and flawless lens, an equally good picture may be secured, provided the proper time is given, as with the more expensive lens. As there are no moving objects in the class of views that the engineer will photograph, exposures may be properly timed.

Shutter.—The shutter should be of the ordinary variety, operated or snapped with a bulb or cable. For rough handling the bulb release is considered the best. There are a number of standard

shutters on the market, any one of which gives entirely satisfactory results. Improvements are being continually made, and it is advisable to purchase the most durable pattern on the market. There is less liability of making errors with the shutter that sets and releases automatically with a bulb or cable. Those that have to be set by hand oft times produce no exposure, the photographer forgetting to set the shutter.

Diaphram.—Most all cameras are now equipped with the iris diaphram, and this attachment is the best with which to contro the stop.

The stop is the technical term for regulating the size of opening in the diaphram. There are two systems of indicating the differen stops. The "Universal Standard" (U. S.) and "f" for focal speec of lens. The following list shows the usual equivalent stops fo both systems.

U. S..................	1.2	2.0	2.5	4	8	16	32	64
f.....................	4.5	5.6	6.3	8	11	16	22	32
Ordinary kodak stops:						1	2	3

Stop U. S. 1.2 gives the largest opening.
Stop U. S. 64 gives the smallest opening.

Manipulation.—The most important factors that enter int making an exposure are:

1. Composition.
2. Distance.
3. Aperture.
4. Time.
5. Strength and direction of light.
6. Phases of views.
7. Recording all operations in the exposure record.

Taking up these operations in their order:

Composition.—A photo should not be looked upon as a miscellaneous lot of black and white spots on a piece of paper. In orde that the photo should properly show the information requirec it should in most instances be taken from some station along th line of work, or from some point which has been definitely locate without the line of work. The most desirable position from whic to make the exposure is one from which professional as well as artistic points may be seen. The selection of such a point is made afte carefully studying the composition of the view as seen in the finde: If a view is required along the survey line, select, if possible, tha station where the light will come from behind or from the sid Carefully study the composition.

If on a survey line, along a stream bank, on the edge of a mes at the shore of a lake or bay, bring the important features into th middle of the finder. No picture should be taken that does not contain some life, as only professionals can make a good picture of sti life. Picket a rodman with a level rod or stadia board of know length on a station 50 or 100′ away on line—or more particularl at the point it is intended to feature. This not only gives life t

ne view, but provides a medium by which distances in the view may e estimated. Have, if possible, one-third of your view composed sky. Balance your picture. Guard against having the center iew obstructed by a 6′ tree 15′ from the camera, while the feature ou are trying to photograph is 100′ away. Such a composition lurs the foreground, reduces the field of view, and, in general, spoils hat might have been a successful photo.

Hold or set the camera level. If it is necessary to obtain some ature that is below or above the outline as shown in the finder, anipulate the shifting front of the camera. Never tip the camera o or down, for to do so will produce distorted photos on account the vanishing point lying outside of the horizontal plane.

Distance.—Ascertain the distance from the camera to the object be photographed. Do this with reasonable care, as too many oor negatives result from carelessness in estimating distances. et the indicator at the proper point on the scale of distance. he nearer the subject is to the camera the more care should be xercised in ascertaining the distance. For universal focus use stop . S. 16, 32, or 64 and set focusing indicator at 25 to 30′.

Aperture and Time.—The aperture (stop) and time of exposure e the governing points in making an exposure.

For a given condition a number of different combinations of erture and time will give satisfactory results. The larger the erture the shorter the time. The smaller the aperture the better ne detail of the picture becomes. In general, it is desirable to use fairly small aperture to get detail and as long a time as conditions ermit.

The correct combination of aperture and time is affected by the se of a tripod, movement of objects, speed of plate or films used, titude, latitude, season of the year, intensity of light, and compo- tion of the picture. This sounds complicated and is for the best sults, but fortunately considerable variation from the best timing ill still produce a fairly good negative for all practical purposes.

Effect of Use of Tripod.—It is advisable to use a tripod for all ngineering photography, as it prevents blurring by movements the camera during exposures and makes it possible to use a small erture, with the necessary time of exposure, to get good detail. the camera is held in the hands, the time of exposure should be 25 sec. or less and the aperture will have to be made large enough allow this speed.

Effect of Motion of Objects.—As a rule, moving objects need not e photographed, but if necessary the following speeds of exposure ill stop motion.

$\frac{1}{25}$ sec. will stop wind in foliage.
$\frac{1}{50}$ sec. will stop pedestrians and slow-moving rigs.
$\frac{1}{300}$ sec. will stop distant trains.
$\frac{1}{500}$ to $\frac{1}{1000}$ a sec. will stop near trains, automobiles, etc.

The aperture must be regulated to allow these speeds.

That is, time governs aperture where motion is encountered. nder most conditions, however, where a tripod is used aperture

governs time and a small aperture is desirable in order to obtai detail. For most landscape engineering survey work a U. S. stc 16, 32, or 64 is used and the time is varied to correspond with tl stop selected. —

Bright sun, use stop U. S. 64 or 32.
Fair light, use stop U. S. 32 or 16.
Moderate light, use stop U. S. 16 or 8.
An aperture of U. S 8 will give moderately good detail.

Speed of Plate or Film.—Different makes have different spee but there is no great variation in the speed of the ordinary roll filr or speed pack films and the following exposure chart is based on tl commercial film in ordinary use.

Effect of Altitude.—Altitude has a marked effect on time exposure. Exposure charts are worked out for sea level.

Wilson topographic surveying quotes E. Deville as stating th: altitude has practically no effect on timing when the sun is near t zenith in the middle of the day but that as the sun approaches t horizon the effect becomes evident. He gives the following relati time of exposure at sea level and 10,000′ altitude.

Altitude of Sun	Relative Time of Exposure,	
	At 10,000 ft. Altitude	At Sea Level
90°	1 second	1 second
40°	1 "	1¼ "
25°	1 "	2 "
15°	1 "	3½ "

The rule generally used for ordinary engineering photography to cut the time of exposure in half when working at an elevation 5000 to 10,000′.

Effect of Latitude.—Exposures at the equator require the shorte timing.

As the latitude increased, the time of exposure increases.

For example, conditions requiring 1/25 sec. at the equator requi ¾ sec. in Alaska.

Effect of Season of the Year.—The summer months require le exposure than the winter months.

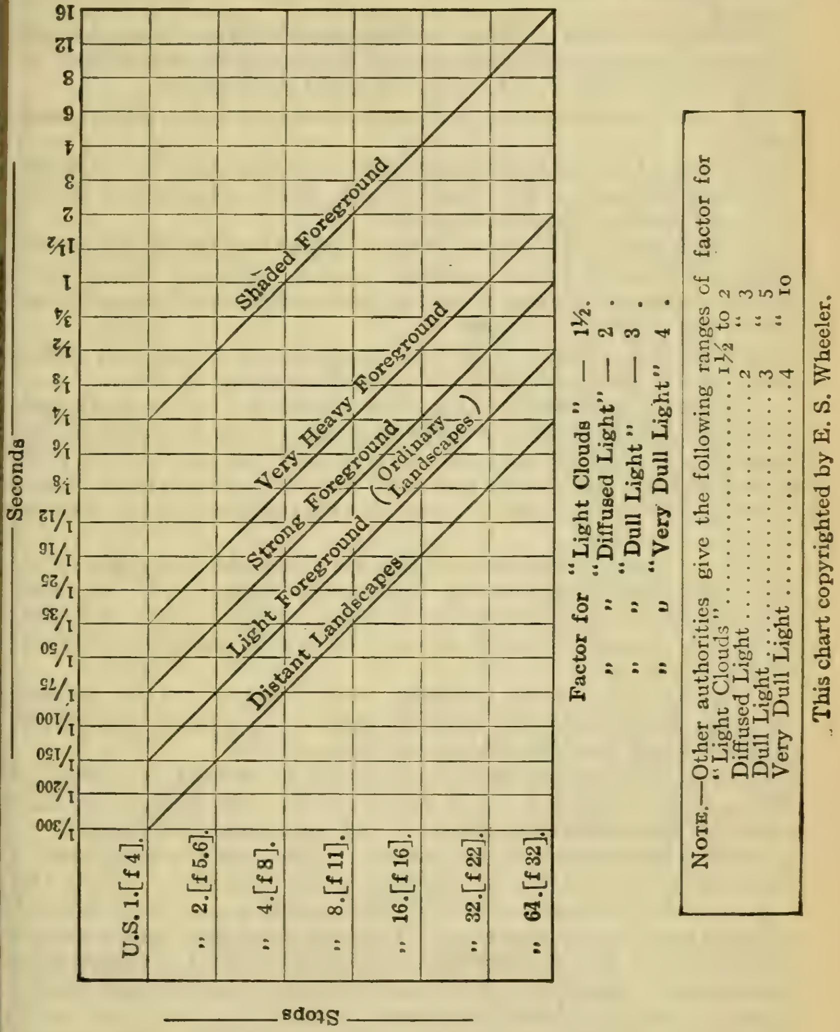
For example conditions requiring an exposure of 1/10 sec. summer will require 1/5 sec. in winter, except that it mu be remembered that snow on the ground changes the classifiacti of "phase" discussed below.

The chart on page 823 is prepared for sea level at average co ditions of latitude and season in the United States and the effe of latitude and season can be disregarded for all practical purpos except for extreme cases, as they have a relatively small effect f this territory as compared to light intensity and phase of the pictu

The extreme variation from the chart will be approximately follows: for winter months along the Canadian boundary, doub

the time of exposure given in the chart. For southern Florida in midsummer use one-half the time given in the chart.

When it is borne in mind that this variation in relative exposure does not ruin a negative, it can be seen that unless these extreme



conditions of combined location and season prevail the chart time without correction should give reasonably good results. Altitude should, however, be considered.

EFFECT OF LIGHT AND PHASE

Light Values.—Judgment and experience are essential if good, average negatives are to be secured. However, the following dis-

cussion of light values of different lights and phases of views may be of use. Five distinct conditions of light are generally taken into consideration when calculating for an exposure.

(A). *Bright Sunlight.*—When the sun is shining brightly in a cloudless sky.

(B). *Light Clouds.*—When a thin film of white clouds partially obscures the sun, but fairly well-defined shadows are discernible.

(C). *Diffused Light.*—An even light but no shadows.

(D). *Dull.*—Sky covered with dull clouds with no sunlight penetrating.

(E). *Very Dull.*—Sky overcast with very dark clouds. Gloomy.

Phases of Views.—For classifying views or subjects in a view—the five following phases are given:

1. *Landscapes.*—This view contains distant landscapes, sea-scapes, snowclad hills, or broad expanses of river scenery. Such views reflect a large percentage of actinic light, and should be short timed or stopped down accordingly.

2. *Light Foreground.*—This view contains open fields and woods, flocks of live stock, buildings, and small expanses of water.

3. *Strong Foreground.*—This view contains a large percentage of foliage, buildings close enough to make strong and distinct outlines, fences, figures, animals, well-defined roadways, rock cliffs, or well-defined hill slopes not over 400′ from the camera, urban scenes where the sky line is serrated with buildings, or full views of concrete structures.

4. *Very Heavy Foreground.*—This view contains close-ups of the following: landscapes having dark-green foliage and shadows, bridges and other structures with heavy shadows, and rock cliffs which are generally located in canyons where considerable direct light is shut out.

5. *Shaded Foreground.*—Under this caption come ravines, wooded hillsides, standing timber, under trees, and small dark box canyons where sunlight is shut out by shadows.

Caution.—Great care must be exercised in making exposures for views under condition 5. Give plenty of time, and should doubt exist double the time taken from the chart and make another exposure.

Bearing in mind the five conditions of light and the five phases of views, enter the chart with the view as an argument. Along this line a number of combinations for time and stop may be had which will give satisfactory negatives. If detail is required, select a small stop, and from this get the time for Bright Sunlight. Should light conditions be other than these multiply the time obtained by the proper factor given below the chart.

For Example.—Condition of light, diffused ("C"). Phase of view, strong foreground. Suppose it is desired to use stop U. S. 8, the time for bright sunlight is given as $\frac{1}{8}$ sec. Multiply this time by 2, the factor for diffused light, getting $\frac{1}{4}$ sec. as the exposure required.

NOTE.—There are a number of meters now published which go into detail as to time, aperture, conditions of light, and phases of view, all of which give excellent results. These may be purchased from most any photo supply depot.

Exposure Record.—In order that the photographer may have something upon which to check up his failures, identify each view in connection with the project in hand, and properly reference them in the files. An exposure record should be used and each exposure carefully recorded. This record may take any number of forms, but from experience the following is suggested, which has been filled out to show how it is intended the columns should be used.

ROLL 36. Exposure Made by Bill Jones ——— Sept. ———

No. of Film	Job	Date	Hour	Light	Stop "f"	Time	Subject. Descriptive Notes
1	Rabbit Ears	5/8	9.00	A	16	1/10	Sta. 1007+40. Looking Az. 170 deg. along tang. Rodman on Sta. 1006.
2	Rabbit Ears	5/8	10.00	B	11	1/4	Old timber br. at Sta. 1020. Camera 60′ to right of 1019–50 looking Az. 130 deg. (out of focus).
3	Rabbit Ears	5/8	10.30	B	22	1/5	Sta. 1025 looking Az. 90 deg., showing proposed Xing of river. Solid rock in extreme left of view.
4	Rabbit Ears	5/8	4.00	A	11	1/10	Sta. 1091 looking Az. 270 deg., showing Amazon Pass, Hopland and Big River Valley.
5	Tyeras Canyon	5/9	10.00	C	8	1 sec.	Sta. 1107–45 looking Az. 210 deg. Dense timber along tangent.
6	Tyeras Canyon	5/9	3.00	D	22	1½	Sta. 1136 looking Az. 226 deg. along tangent showing houses on right-of-way. Close up view. Rodman on Sta. 1137.

DON'TS

Don't expect good results from snapshots taken before 9 a. m or after 5 p. m. even with sun shining brightly.

Don't try to make snapshots under trees or in a shadow. Make a time exposure, resting the camera on a firm base, or, better still, use a tripod. Get the proper time from the chart.

Don't hold the camera in your hand when making exposures over 1/25 sec.

Don't attempt to make snapshots indoors.

Never face the camera at the sun unless necessary and then be sure to shade your lens from direct rays of the sun.

Always use small stops if detail is desired.

Don't give time exposures to distant landscapes. The farther away the subject the less time is required.

Buy only fresh films which will exactly fit your camera, and observe the date on same beyond which no guarantee of value is given.

Always turn the key bringing a new unexposed film into correct position after having made an exposure.

After having exposed a roll take it from the camera, and before putting in a new roll, examine the lens, try shutter, and blow out any particles of dust that might have worked into the bellows.

If, after having made an exposure, the least doubt arises as to whether it was an overexposure, underexposure, or double exposure, calculate for a stop and time, and proceed to make an exposure that will be satisfactory. This advise is of particular value to engineers, as it is not infrequent that the picture most needed is the one failure on the roll. The second exposure costs but 10 cts. To secure it after the camp or work has been abandoned may cost a hundred dollars.

Developing.—Fairly good prints may be secured from average negatives, but the best prints are obtained from good negatives. To obtain good negatives the exposure must be reasonably correct, and development must be done with fresh and pure chemicals in quantities called for in the respective formulas recommended by the makers of the plates or films used.

The simplest, most convenient, and most certain method of development that has been worked out for films is what is generally known as tank development.

The equipment necessary properly to handle films of the size suggested in the beginning of this article is as follows:

1 E. C. Eastman tank No. 5E7 complete.
1 5 by 7 gutta-percha tray.
1 32-oz. measuring glass.
1 stirring rod.
1 thermometer.
1 or more pairs of film clips.
1 dripping pan enameled, about 9 by 12″.

The chemicals required for one roll of films are:
1 Tank developing powder for 5 by 7″ tank.
4 oz. of hypo with acidifier.

Plenty of clear pure water having a temperature of 65°F.

As no dark room is required, the development may be carried on at any time, and the process is as follows.

Dissolve the developing powder as per directions, using the developing tank, testing the same with the thermometer so that the solution when ready shall have temperature of 65°F. Set this aside.

Thoroughly rinse the measuring glass, and in 16 fl. oz. of water dissolve the 4 oz. of hypo and acidifier. Pour this solution, known as fixer, into the 5 by 7 tray. Thoroughly rinse the measuring and glass stirring rod.

Prepare the films as directed in instructions accompanying the developing tank outfit, and wind it onto the opaque curtain.

This operation takes place in the lightproof box.

Remove the spool containing the curtain and film, and place it in the tank containing developing solution, firmly fastening the top on the tank. Turn the tank end for end two or three times, holding it vertically for 5 or 10 sec. each time, so as to expel all air from between the folds of the curtain, and insure complete contact between the developing solution and the film. At the moment of immersion, record the time, and permit development to go on for the specified time given for the temperature of the solution. If using Eastman tank developing powder, and solution is 65°F., the time of development should be 20 min. Invert the tank every 5 or 7 min. so that even development may be obtained.

Development having been completed, fill the dripping pan with fresh water, take the spool from the tank, and, working rapidly, unroll the apron or curtain until the end of the film is visible. Firmly clamp a film clip to this end of the film. Now lift the end of the film by this clip, unrolling it from the curtain until the other end of the film is free, and clamp another clip on this end. Rinse the film in the dripping pan of fresh water, running it through three or four times. Change to fixing bath, and run film through rapidly three or four times, making sure that the entire surface of the film is flooded with the solution, thus insuring that development is completely arrested.

Continue washing in the fixer until the film is clear. This will take from 7 to 10 min. Rinse in clear, cool, running water for ½ hr., or in 20 changes of water allowing the film to remain 3 to 5 min. in each change. After rinsing, suspend the film from a wire or hook, so that the same will hang free and permit it to dry. Do not touch the surface until perfectly dry. If the film has a tendency to curl during drying, leave it alone. The weight of the clip at the lower end will be sufficient to correct this.

When perfectly dry, trim the ends so as to leave as much unexposed film as there is between the exposures. Before cutting the film, place it on a table, back up, and under vertical views, or to the left of horizontal views, inscribe the information contained in the eighth column of the exposure record, together with the index or filing number, using india ink. Place the index or filing number in a convenient space, usually the upper left-hand corner.

Cut the film, taking particular care that in so doing the legend and the view to which it applies are together. Do not use scissors to cut the film, as this, unless cleverly done, is apt to produce an irregular edge which is difficult to fit into the mask. Use straight edge and sharp-pointed knife, or better still a trimmer, the latter costing about $1.75.

If all operations to this point are correctly performed, films will be uniform, have a neat and workman-like appearance, and bear complete information as to date, subject, station from where taken, and index number. The film so labeled will be special, specific, and sufficient; special because it applies to a certain project, specific because it pertains to a particular point of feature of the project, and sufficient because it gives complete information.

Causes of Failures.

Not sharp:

1. Objects moving or moving too fast.
2. Out of focus.
3. Camera being moved during exposure.

Undertimed:

1. Use of too small stop.
2. Light too weak.
3. Exposures too short.

No exposure:

1. Failure to set shutter.
2. Failure to release shutter.
3. Something in front of lens.

Double exposure:

1. Failing to wind up film after making exposure.

Fogged:

1. Camera leaks light.
2. Carelessness in loading or unloading.
3. Taking pictures against sun.

Overtimed:

1. Stop too large.
2. Too much time given.

Printing.—Equipment additional to that required for fil developing:

1 Printing frame 5 by 7.
1 Gutta-percha tray 5 by 7.
1 Orange light.
1 Dish pan from camp kitchen.
Developing powders. (One tube of M-Q develops 18 prin of the size herein mentioned.)
4-oz. hypo with acidifier.
4-oz. bottle potassium bromide, 10% solution.
Quantity of 5 by 7 developing out paper, Azo preferred.

Procedure.—Prepare the developer by dissolving the conten of the tube as per direction thereon, and pour the solution into or tray, not the one used for fixing bath. In order that no doubt ma arise as to which tray is for the fixer, take a sharp instrument an scratch the letter H in the bottom, so the same may be seen whe the tray is in use.

Prepare the fixing bath by dissolving the 4 oz. of hypo an acidifier in 16 oz. of water. The temperature of the developing solu tion should be normal, or 65°F. If too cold it retards the develop ment, and if too warm the development is too rapid, and prints a apt to show steaks. A warm developing solution, fixing bath, rinsing bath produces blisters, due to too rapid action, which pro duces gas under the filament on the paper. The fixer and rinsin water may have a temperature as low as 40°F. In fact, the write has had the best success working with the fixing bath and rinsin water at this temperature. Prints may be left in running water this temperature all night without blistering or raveling.

Arrange the pans and trays in a row in the following order from ·ft to right: (1) dish pan of water in which to rinse the hands and nished prints, (2) dripping pan of water in which to immerse the rints before placing them in the developing solution, (3) tray conaining developing solution, and (4) tray containing fixing bath.

Provide a towel to dry the hands on before taking up new, ndeveloped prints.

Take one sheet of paper and cut the same into strips about ½″ ide, and keep the same in a lightproof box. These strips are for naking a trial of the negative, if doubt exists as to the length of me to print. Clean the glass of your printing frame and provide mask having a width inside of 4⅛″, if using 4¼ by 6½ films. 'he mask should be open at one end so as to allow the legend, which as previously been written or printed on the film, to print. The nask should be provided with paper guides of about 2 by ¼″ pasted n one side and top at the corner back from the edge of the opening— distance equal to the white margin that should surround the print n the top and the two sides. These guides are generally the thickess of medium-weight detail paper, and serve to hold the paper and lm together when the same are placed in the frame, and also during rinting. Printing frames are now made, provided with adjustable uides by means of which any desired size of mask may be had. 'hese are convenient, and their purchase is suggested.

Working in subdued light only, and with orange light in position, lace the film and a sheet of paper in the printing frame, and print n accordance with the light used and density of the film.

Printing should be done in accordance with directions contained n the container of the paper purchased. Artificial light is prefrable to daylight, and electric, gas, or oil lamps may be used. The roper time and distance from light are always given by the manuacturer of the paper.

If daylight be used, hang a sheet over the north window so as o diffuse the light and by experiment deduce correct time for printng. Usually medium negatives will print in such a light in from 2 o 4 sec. Note the time taken to print, and remove the paper, and inse in pan 2, in order to moisten and prepare the surface. Immerse n the developing solution, tray 3. When the desired tone is btained take the print from the developing solution, rinse for a econd or two in tray 2, and then immerse in fixing-bath tray 4. hould abrasion marks appear on the print, add from 5 to 10 drops f the 10% solution of potassium bromide to the developer. This vill make the development a little slower, but will correct this rouble.

Prints should be left in the fixing bath for 20 min. At the end f this time, remove them and place in rinsing bath, pan 1. If runing water is available, rinse the prints for 1 hr., or longer if possible. f no running water is at hand, rinse in a dozen changes of water, eeping the prints moving so as to remove all traces of hypo.

When washed, collect the prints as you would a deck of cards, nd taking not more than a dozen at a time, lay them on one fold f a towel, placing another fold over them. With an ordinary rolling in, or in the absence of this, a round bottle, roll and press out the

excess water. Separate and lay them face down on cheese cloth muslin, or even a clean piece of paper which has been placed on a smooth surface, and permit them to dry. When thoroughly dry place on a table face down and draw them separately backward and upward under a not too sharp straight edge or triangle. This will leave them either flat or slightly convex. The prints may now be trimmed as desired.

Two grades of paper are recommended—one grade for average negatives, and one for contrasty negatives. Provide sufficient paper based on the ratio of average to contrasty negatives of 6 to 1. There are several grades of paper with a number of finishes. The glossy finish generally gives the best results for engineering purposes, and its use is recommended. To go to the expense of providing more grades of paper than above mentioned is an unnecessary refinement.

With practice the operator will soon be able to judge the density of negatives so that the use of trial strips will rarely be necessary. After sufficient practice, and when the operator is able to judge his negatives so as to print to within a reasonable degree of correctness, printing should be carried on until all the prints required have been made, inserting them in a lightproof box or between the leaves of a book. Then develop the batch, and perform all operations through to the hypo bath. The batch after 20 min. may be taken from this bath and placed in rinsing water. The white light may be turned on as soon as all are in the hypo. By this method a large number of prints may be handled in a short time.

Rinse the hands each time after having them in hypo, for hypo is a strong restrainer, and should you handle prints without so doing white finger prints will appear when development is carried on.

After developing films or prints, wash up all equipment and scrub hypo and developing trays with salt—this will remove all traces of chemicals.

CHAPTER XIII

THE SURVEY

The chapter on Survey will be handled under two main divisions:
a. Improvement of existing roads.
b. Location of new roads.

FOR THE IMPROVEMENT OF EXISTING ROADS

As the survey furnishes the information for the design, it must be carefully made in regard to the essential features. These are alignment, levels and cross-sections, drainage, information concerning foundation soils, available stone supply, available sand, gravel, filler, etc.; direction and amount of traffic, railroad unloading points, the location of possible new sidings, and such topography along the road as will have a bearing on the design. The survey should be made not more than a year before construction starts and during the open season, as a snowfall of any depth makes the work unreliable and only fit for a rough estimate. When contracts based on winter surveys are awarded it is always necessary to take new cross-sections to insure a fair estimate of the excavation.

A party of five men is a well-balanced force for surveys of this character.

Force	Equipment	Stationery
Engineer	Transit	Reports
Instrument man	Level	Pencils
Three helpers	2 100′ steel tapes	Notebook
	3 50′ metallic tapes	U. S. Geological Survey map.
	3 pickets	
	2 level rods	Stakes
	Pocket compass	For preliminary survey:
	Hatchet	110 stakes per mile
	Sledge	For construction:
	Ax	220 stakes per mile
	Keel	

The Center Line.—The placing of the center-line hubs (transit points) requires good judgment and should be done by the chief of the party. In locating them he considers the principles of alignment discussed in Chap. II. The hubs are placed at tangent intersections and sometimes at the P. C.'s and P. T.'s of curves and are referenced to at least three permanent points that will not

be disturbed during construction (see sample page of notes, Fig. 270).

The deflection angles at the tangent intersections are usually read to the nearest minute, taking a double angle to avoid mistakes; the magnetic bearing of each course is recorded. For all deflection angles over 4° it is good practice to figure and run in on the ground the desired curve. Curves with central angles of less than 4° can be run in with the eye during construction.

The center line is marked at intervals of either 50 or 100′ (see cross-section, p. 833) in any convenient manner; the alignment of these points should be correct to within 0.2 and the distance along the line to within 0.1 per 100′ of the length; any attempt to get

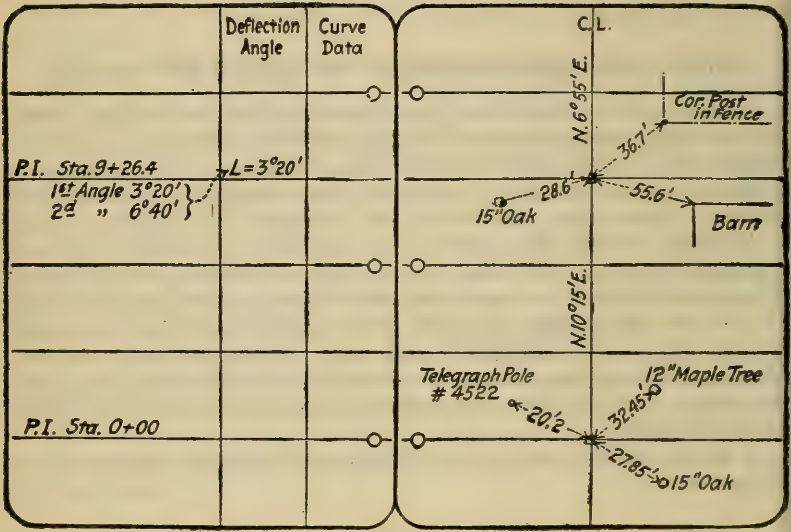


FIG. 270.—Alignment notes.

more accurate stationing is a waste of time. The chaining may be done on the surface of the ground up to a grade of 5% with no objectionable error; beyond that slope, however, the tape should be leveled and plumbed. Steel tapes should be used for chaining the center line and referencing the hubs.

A convenient method of marking the actual center-line stations is to use a nail and piece of flannel, red flannel for the 100′ stations and white flannel for the intermediate 50′ stations, if needed. Where the soil is sandy or muddy, and these nails would be kicked out or covered, a line of stakes can be set outside of the traveled way on a specific offset from the center line. If an offset line is used, however, the chaining of all curves should be done on the center line to insure a correct center-line distance and the stakes placed radially on the desired offset. Railroad spikes make good permanent transit points and are easily placed.

At the same time that the line is run it is just as well to paint the 100′ station numbers on any convenient place where they

can be readily seen, as stations marked in this manner make it much easier to sketch in the topography than if marked in chalk on stakes. Also, if the stations are permanently marked it is easier for the construction engineer to pick up the transit points at some future time.

A party of five men will run from 2 to 4 miles of center line a day, the speed depending upon the number of curves and length of tangents, if the hubs have been previously placed and referenced. If the hubs are placed at the same time the line is run, the work is greatly delayed.

Two men can place and reference the transit points at the tangent intersections at the rate of from 4 to 10 miles per day.

Levels and Cross-sections.—Bench levels are run in the usual manner; the levels will be sufficiently accurate if the rod is read

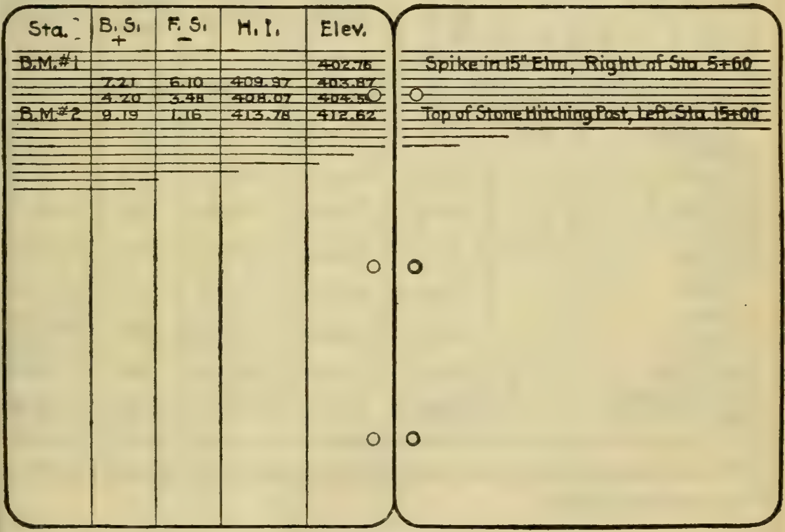


FIG. 271.—Bench level notes.

to the nearest 0.01′; for such work any good level and a self-reading rod graduated to hundredths are satisfactory. Benches are established at intervals of 1000 to 1500′; they must be substantial, well marked, and so situated as not to be disturbed during construction. A small railroad spike in the root of a tree, a large boulder, or the water table of a building make good benches.

The bench levels may be referred to some local datum in general use or to the U. S. levels, or the datum can be assumed. In running bench levels it is better to use each bench as a turning point, as side-shot benches my be wrong even if the line of levels is correct.

Cross-sections are taken at either 100 or 50′ intervals, at all culverts, possible new culvert sites, and any intermediate breaks not shown by the normal interval. Enough sections are taken to show the constantly changing shape of the road.

The distance of the shots from the center line of the road is rea to the nearest 1.0′ where the ground has no abrupt change of slop and to the nearest 0.5′ where there is a well-defined abrupt chang The elevations are read to the nearest 0.1′. The sections shoul extend from fence line to fence line, or in villages from sidewal to sidewalk, and the position of the pole lines, tree lines, curb etc., noted. Engineers differ as to whether the sections should b taken at a normal interval of 50 or 100′.

Table 136 gives the difference in the computed quantity of eart work, using 50 and 100′ sections with intermediate sections at wel defined breaks in the grade.

TABLE 136

Name of Road	Length Figured	Character of Road	Excavation 50′ Section	Excavation 100′ Section	Approximate Difference	Per cent of Difference
			Cu. Ft.	Cu. Ft.	Cu. Ft.	
Scottsville Mumford ...	1 mile	flat	61,444	61,995	550	+ 9/10%
Scottsville Mumford ...	1 "	hilly	111,109	111,700	600	+ ½ %
Leroy Caledonia	1 "	rolling	57,840	60,560	2700	+ 4¾ %
*Leroy Caledonia	¾ "	flat	77,841	78,659	800	+ 1 %
Clarence Center	1 "	rolling	73,727	73,048	700	− 1 %
Clarence Center	1 "	flat	38,037	39,415	1400	+ 3 7/10%
Lockport Tonawanda ...	1 "	flat	59,096	59,470	400	+ 7/10%
*East Henrietta Rochester	1 "	rolling	37,275	36,075	1200	− 3¼ %

The following tabulation shows the variation for shorter sectio of the starred roads.

Name of road and Station to Station	Quantities by 50′ Sections	Quantities by 100′ Sections	Approximate Difference	Per cent of Difference
	Cu. Ft.	Cu. Ft.	Cu. Ft.	
Leroy Caledonia, 80–90 ...	19,151	19,525	400	+ 2 %
" 90–100 ...	21,915	23,415	1500	+ 7 %
" 100–110 ...	21,555	20,689	900	− 4 %
" 110–120 ...	15,220	15,030	200	− 1 3/10%
Total and averages .	77,841	78,659	800	+ 1 %
East Henrietta Rochester, 0–19 ...	14,625	14,300	300	− 2 %
" 32–49 ...	11,950	11,575	350	− 3 %
" 49–66 ...	10,700	10,200	500	− 5 %
Total and averages .	37,275	36,075	1200	− 3¼ %

The question of quantities is not the only factor in determining the interval. Where it is important to fit the local conditions, as in a village, or to utilize an old, hard foundation, the designer is helped by 50′ sections.

In taking cross-sections the work becomes mechanical, and unless the engineer in charge is unusually alert to all the intermediate changes better results will be obtained by the use of the shorter interval. For these reasons the author believes that a 50′ interval is advisable except on long, uniform stretches of road.

A party of three men will run from 4000 to 7000′ of 50′ cross-sections per day; a party of four men from 5000 to 9000′ depending on the country.

Sta.	B.S.	F.S.	H.I.	Elev.	Left				C.L.	Right				
B.M.*3				926.32										
10+00	5.41		931.73		926.7 / 5.0 / 40	926.4 / 5.3 / 14	925.7 / 6.0 / 12	926.5 / 5.2 / 5	926.6 / 5.1 / 0	926.3 / 5.4 / 5	926.2 / 5.5 / 9	925.8 / 5.9 / 11	926.4 / 5.3 / 19	925.2 / 6.5 / 24
10+50					926.2 / 5.5 / 28	925.7 / 6.0 / 20	925.2 / 6.5 / 14	925.4 / 6.3 / 11	925.7 / 6.0 / 8	925.7 / 6.0 / 0	925.4 / 6.3 / 8	924.7 / 7.0 / 11	924.7 / 7.0 / 12	924.1 / 7.6 / 20	923.7 / 8.0 / 28
T.P. +65 Rock on Rt.		2.10		929.63										
11+00	1.32		930.95		922.8 / 8.2 / 30	922.3 / 8.7 / 20	921.9 / 9.1 / 13	922.2 / 8.8 / 9	922.4 / 8.6 / 5	922.5 / 8.5 / 0	922.0 / 9.0 / 10	921.7 / 9.3 / 14	922.1 / 8.9 / 18	923.0 / 8.0 / 30	

FIG. 272.—Cross-section notes.

Drainage.—The drainage notes show the position and size of all the existing culverts; the area of the watersheds draining to them and a recommendation of the size culvert to be built; the location, drainage area, and size of desirable new culverts; the necessity for outlet ditches and their length, if required; the elevation of flood water near streams, and the condition of the abutments and superstructure of long-span bridges. The cross-section levels are supplemented to show these points fully. Where the U. S. geological maps are available the areas of watersheds can be easily determined; where no such maps have been made the drainage areas can be easily mapped with a small 15″ plane table oriented with a magnetic needle; the distances can be paced and the divides determined with a hand level. One inch to 2000′ is a convenient scale.

The drainage scheme should be carefully worked out by the chief of party, as the possibilities of friction with local people are greater on this part of the design than any other. In the chapter on Drainage this fact was mentioned and designers were cautioned not to use new culverts unless necessary. For special features of bridge survey see page 942.

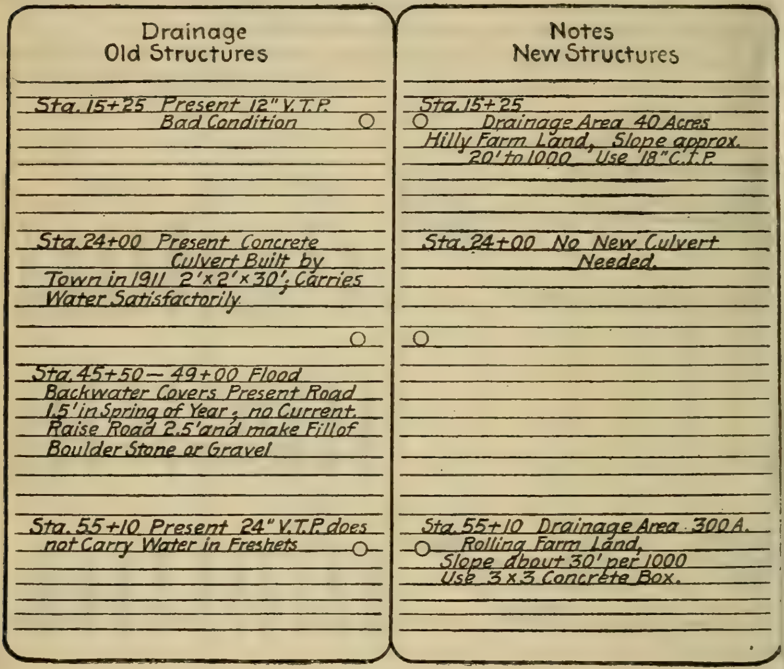


FIG. 273.

Topography.—The topography notes show the features of the adjacent territory that might affect the design. These include the location of buildings, drives, intersecting roads, streams, railroads poles, trees, sidewalks, crosswalks, and property lines. The names of property owners are recorded.

A simple method of locating these points is to refer them directly to the previously run center line by right-angle offsets; such notes are easily taken and quickly plotted.

In taking the topography the plus stationing along the center line and the offset distances to all points inside of the road fences should be measured by tape to the nearest foot; the distances to and the dimensions of buildings, etc., outside of these limits can be paced or estimated; the bearings of the property lines can be read near enough with a pocket compass, except for right-of-way surveys, which are described on page 840.

The instruments needed for work of this kind are a pocket compass reading to 2°, steel picket, and metallic tape.

Two experienced men will take from 2 to 4 miles of topography a day except in villages, where from ½ to 1 mile is average speed.

Direction and amount of traffic is determined by inspection and by a study of the traffic census map for the locality considering the relation of the road in question to adjacent completed roads. (See page 32 for a discussion of Estimating Future Traffic.)

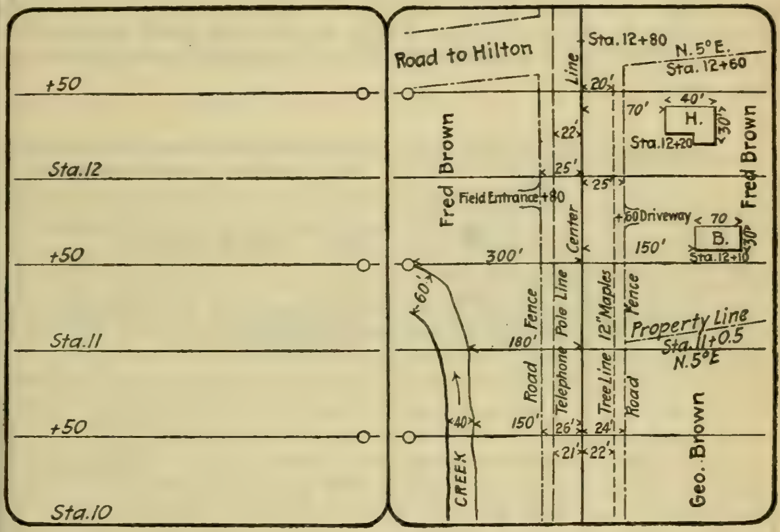


FIG. 274.—Topographic Notes.

To illustrate the information required, an extract from the survey report of the Fairport Nine Mile Point Road is given below:

Fairport Nine Mile Point Road Traffic Report. Heavy Hauling. The direction of heavy hauling on this road is approximately as follows:

1. Sta. 195 to Sta. 0 toward Fairport.
2. Sta. 195 to Sta. 400 toward Webster.
3. Sta. 580 to Sta. 400 toward Webster.

This divides the road into three sections for the determination of the ruling grades.

The ruling grades for Sec. 1 will be determined by the hills at Stas. 10 and 48 and probably will be limited to 5%.

The ruling grade for Sec. 2 will be determined by the knolls at Stas. 267, 285, and 300.

The ruling grade for Sec. 3 will be determined by the hill sat Stas. 445 and 494.

The team traffic is medium-heavy Stas. 90 to 0; light, Stas. 270 to 90; medium, Stas. 270 to 375; heavy, Stas. 375 to 386; very heavy, equivalent to city street, Stas. 386 to 408; medium heavy, Stas. 408 to 450, and light, Stas. 450 to 580. Macadam construction will not be suitable Stas. 386 to 408.

The automobile pleasure traffic will be largely through traffic and probably fairly heavy.

For reconstruction designs traffic census counts are usually available see page 31.

Foundation Soils.—The notes on soils show the character, width, and depth of the existing surfacing material and the kind of underlying material. This feature of the survey is important, as it governs the thickness of the pavement, and, to a certain extent, the position of the grade line where an existing solid foundation can be utilized and the thickness of the improved road reduced to a minimum.

Soil Notes				Foundation Recommendations
Sta. to Sta.		Surface Mat.	Sub Surface	
0	30	Sand & Gravel	Sand & Gravel	Total Thickness Macadam 7"
30	31	Clay & Gravel	Clay 1' down	" " " 12"
31	36	Clay	Clay	" " " 15"
36	40	Gravel 8" deep	Wet Clay	Underdrain on Rt Stone 22" deep
40	41	" 4" "	Clay Loam	Fill at this Point " 9" "

FIG. 275.—Notes on foundation soils.

Even with a careful soil examination it is impossible to make the design of the foundation definite, as mentioned on page 437, but the quantity of the material that will be needed can be estimated very closely.

The subsoil can be readily examined by driving a 1½ or 1" steel bar to the required depth, which is usually not over 4.0 to 5.0' even in cuts, removing the bar and replacing with a ¾" gas pipe, which is driven a few inches and withdrawn. The core will give a fair idea of the material to be encountered.

Where rock is encountered, the elevation of the outcrop is shown, and if the rock underlies the road for any distance within 2 or 3' of the surface, this depth is determined by driving bars. Sample notes are shown beyond.

Station	Left	Center Line	Right
62	$\frac{3.5'}{20}$	$\frac{2.5'}{00}$	$\frac{0.5'}{20}$
63	$\frac{1.5'}{25}$	$\frac{1.2'}{00}$	$\frac{1.0'}{22}$

The note $\frac{3.5'}{20}$ means that 20′ to the left of the proposed center ne of the improvement the rock is 3.5′ below the present surface; om these notes the rock can be readily plotted on the cross-ctions. Its character can be determined from adjacent outcrops from test pits, if required.

Location and Character of Materials.—The selection of materials nd the estimate of the construction cost depend on a knowledge the available materials and their location relative to the road.

Provided these data have not been well gathered on the prelimi-ary investigation work, it should be obtained at this stage. The ethods were described in chapter on Preliminary Investigation ut will be repeated at this point for convenience.

Unloading Points for Freight.—Provided U. S. geological maps e obtainable, the position of sidings may be marked on the heets. The notes for each siding show its car capacity, whether not an elevator unloading plant can be erected, and if hand nloading is necessary whether teams can approach from one de or two. They should also show any coal trestles that can e utilized in unloading, and the location and probable cost of ny new sidings that will materially reduce the length of the haul. anal or river unloading points are shown in the same manner.

Sand, Gravel, and Filler Material.—The position of sand and ravel pits and filler material are noted with their cost at the it; if no local material is available the cost f.o.b. at the nearest ding is given.

Stone Supply.—Provided imported stone is to be used the work s simplified to determining the rate f.o.b. to the various sidings or the product of the nearest commercial stone-crushing plant hat produces a proper grade of stone.

In case local stone is available the location of the quarries or utcrops is shown, the amount of stripping, if any, and the cost f quarry rights. If the estimate will depend upon rock owned by single person, an option is obtained to prevent an exorbitant aise in price.

For field or fence stone a careful estimate is made of the number f yards of boulder stone available, the owners' names, what they vill charge for it, the position of the fences or piles relative to the oad, or side roads, and if the fences are not abutting on a road or ane the length of haul through fields to the nearest road or lane. As fences are usually a mixture of different kinds of rock, the ngineer estimates the percentage of granite, limestone, sandstone,

etc., and the percentage that will have to be blasted or sledged i order to be crushed by an ordinary portable crusher. The amoun of field stone required per cubic yard of macadam is given in est mates (p. 1130). If there is a large excess of stone a careful estimat need not be made, only enough data being collected to determin the probable position of the crusher set-ups and the average hau to each set-up. If a sufficient supply is doubtful, a close estimat is made as outlined above and options obtained from the variou owners.

Samples of the different rocks are tested (see Materials).

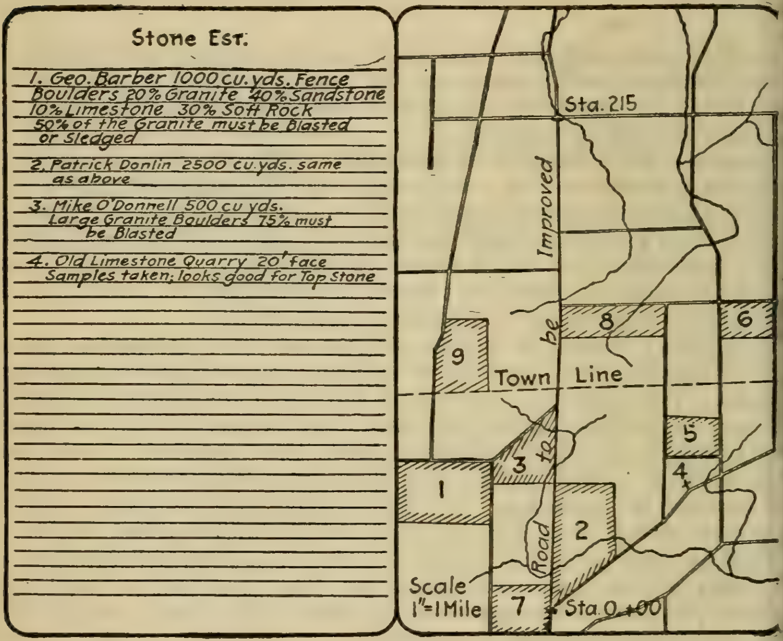


FIG. 275*A*.—Location of local materials.

Cost of Preliminary Surveys.—Preliminary surveys of the precec ing description should be made at a speed of from 2 to 4 miles pe week at a cost of from $70 to $150 per mile, allowing $10 per da for the engineer, $7 for the instrument man, $4 per man for thre laborers, $2 per day board per man, and $4 per day for livery.

Right-of-way and diversion-line surveys are often needed, bu are usually not made at this time; if the designer believes tha additional land must be acquired or that a diversion line is necessar he indicates the information desired and the surveys are made.

Right-of-way Surveys.—These surveys are used not only t show the amount of land to be acquired, but also the damage t property from altering the shape of a field, cutting a farm in twc changing the position of a house or barn relative to the road, etc.

The acreage to be taken is shown by an ordinary land surve in which the road lines, property lines, corners, etc., are locate

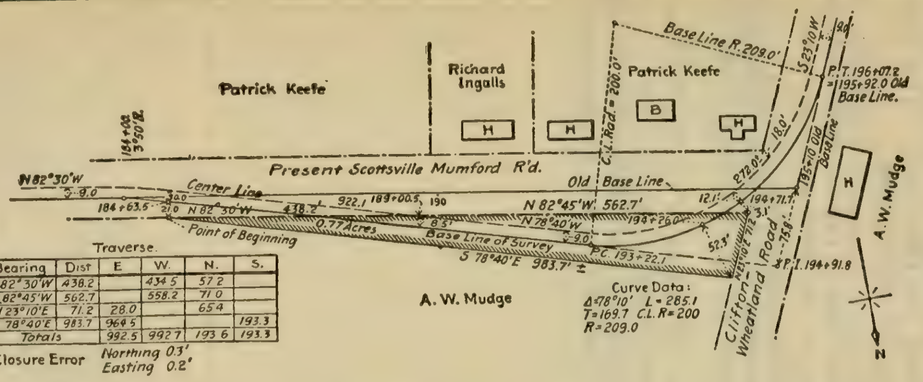
n relation to the proposed center line of the improvement, and heir lengths and bearings carefully determined. It is often ifficult to locate the road boundaries, as town records are care-essly kept and there is a general tendency to encroach on the oad. As the amount paid for new right of way is rarely settled n an acreage basis, it is customary to take the existing fence nes as the road line unless it is very evident that the fence has een moved. This produces better feeling on the part of the roperty owner and does not affect the price paid. The lines etween adjoining properties are usually well defined.

In cases where an orchard is damaged the position and size of he trees are noted; where a field or farm is cut the whole field is hown, with the shape and acreage of the pieces remaining after he land actually appropriated has been taken out.

As is usually done in all land surveys, the parcel to be bought s traversed and the survey figured for closure error to insure he description against mistakes.

The standard form of map and description of the N. Y. State Department is shown in the following illustration: No. 276.

Figure 276 A shows another simple method which ties in the back line by offset distance. This method is easier and serves the purpose very well.



Bearing	Dist	E	W.	N.	S.
N82°30'W	438.2		434.5	57.2	
N82°45'W	562.7		558.2	71.0	
N23°10'E	71.2	28.0		65.4	
S78°40'E	983.7	964.5			193.3
Totals		992.5	992.7	193.6	193.3

Closure Error Northing 0.3' Easting 0.2'

FIG. 276.—Land to be Acquired for the Scottsville-Mumford State Highway, Monroe County: Route No. 16, Section No. 1, from A. W. Mudge.

All that piece or parcel of land situate in the Town of Wheatland, County of Monroe, State of N.Y., for the Scottsville-Mumford State Highway, as shown on the accompanying map and described as follows:—

Beginning at a point in the northerly boundary of the existing Scottsville-Mumford highway, 21.0 feet northerly, measured at right angles, from station 184+63.5 of the survey base line of the proposed Scottsville-Mumford State Highway (Route No. 16, Section No. 1), and 30.0 feet distant northerly, measured at right angles, from the hereinafter described center line of the said proposed State highway; thence N. 82° 30′ W., along the northerly boundary of the said existing Scottsville-Mumford Highway; 438.2 feet, to a point 8.5 feet distant, southerly, measured at right angles, from station 189+00.5 of the said base line; thence N. 82°45′ W. along the northerly boundary of the said highway, 562.7 feet; to a point 3.1 feet distant northwesterly, measured radially, from station 194+71.7 of the said base line and 12.1 feet distant; measured radially, from the said center line; thence N. 23° 10′ E. along the easterly boundary of the existing Wheatland-Clifton Highway, 71.2 feet to a point 52.3 feet distant northerly, measured radially from station 194+26 of the said base line; thence S. 78° 40′ E. 983.7 ± feet to the point of beginning; being 0.77 acres more or less.

The above mentioned center line is a portion of the center line of the said proposed Scottsville-Mumford State Highway (Route No. 16, Section No. 1) as shown on a map on file in the office of the Clerk of Monroe County, and is described as follows:—

Beginning at a point 9.0 feet distant southerly, measured at right angles, from Station 183+00 of the said base line; thence N. 82° 30′ W. 163.5 ft.; thence N. 78° 40′ W. 922.1 feet; thence curving to the left with a radius 200 feet; 272 ± feet to a point 9.0 feet distant south-easterly, measured radially, from Station 196+07.2 of the said base line (=195+92.0 old base line), thence S. 23° 10′ W.

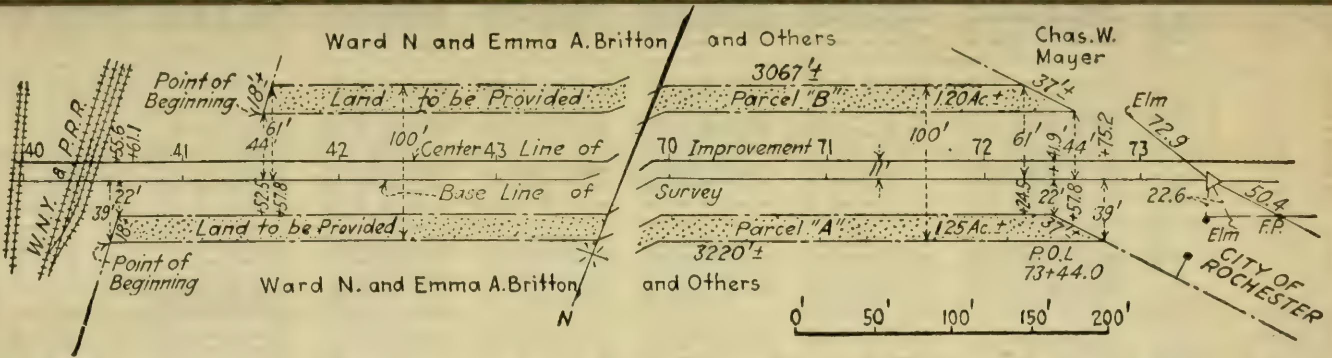


FIG. 276A.—State of New York, Department of Public Works, Bureau of Highways, land to be provided for the Rochester-Scottsville Pt. I C. H. 63, from Ward N. Britton, Emma A. Britton and others (reputed owners).

All those pieces or parcels of land situate in the town of Chili, County of Monroe, as shown on the accompanying map and described as follows:—

Parcel "A"

Beginning at a point in the dividing line between the lands of Western New York and Pennsylvania Railroad Co. on the east and Ward N. Britton, Emma A. Britton and others on the west, said point being northwesterly 39 ft. at right angles from base line sta. 40 + 55.6; thence southerly 18 ft. ± along the said dividing line to its intersection with the northerly boundary line of the existing highway, said point being northwesterly 22 ft. at right angles from base line sta. 40 + 61.1; thence southwesterly along the said northerly highway boundary to its intersection with the dividing line between the lands of Ward N. Britton, Emma A. Britton and others on the north and the City of Rochester on the south, said point being northwesterly 22 ft. at right angles from base line sta. 72 + 41.9; thence northwesterly 37 ft. ± along the said dividing line to a point northwesterly 39 ft. at right angles from base line sta. 72 + 75.2; thence northeasterly 3220 ft. ± to the point of beginning, being 1.25 acre more or less.

The above mentioned base line is a part of the base line of the proposed Rochester-Scottsville County Highway No. 63, as shown on a map on file in the office of the clerk of Monroe County.

Made by—Koerner
Traced by—Neverett
Checked by—Facer

TABLE 137.—HORIZONTAL DISTANCES AND ELEVATIONS FRO
STADIA READINGS[1]

	0°		1°		2°		3°	
Minutes	Hor. Dist.	Diff. Elev.	Hor. Dist.	Diff. Elev.	Hor. Dist.	Diff. Elev.	Hor. Dist.	Diff. Elev.
0	100.00	0.00	99.97	1.74	99.88	3.49	99.73	5.23
2	100.00	0.06	99.97	1.80	99.87	3.55	99.72	5.28
4	100.00	0.12	99.97	1.86	99.87	3.60	99.71	5.34
6	100.00	0.17	99.96	1.92	99.87	3.66	99.71	5.40
8	100.00	0.23	99.96	1.98	99.86	3.72	99.70	5.46
10	100.00	0.29	99.96	2.04	99.86	3.78	99.69	5.52
12	100.00	0.35	99.96	2.09	99.85	3.84	99.69	5.57
14	100.00	0.41	99.95	2.15	99.85	3.90	99.68	5.63
16	100.00	0.47	99.95	2.21	99.84	3.95	99.68	5.69
18	100.00	0.52	99.95	2.27	99.84	4.01	99.67	5.75
20	100.00	0.58	99.95	2.33	99.83	4.07	99.66	5.80
22	100.00	0.64	99.94	2.38	99.83	4.13	99.66	5.86
24	100.00	0.70	99.94	2.44	99.82	4.18	99.65	5.92
26	99.99	0.76	99.94	2.50	99.82	4.24	99.64	5.98
28	99.99	0.81	99.93	2.56	99.81	4.30	99.63	6.04
30	99.99	0.87	99.93	2.62	99.81	4.36	99.63	6.09
32	99.99	0.93	99.93	2.67	99.80	4.42	99.62	6.15
34	99.99	0.99	99.93	2.73	99.80	4.48	99.62	6.21
36	99.99	1.05	99.92	2.79	99.79	4.53	99.61	6.27
38	99.99	1.11	99.92	2.85	99.79	4.59	99.60	6.33
40	99.99	1.16	99.92	2.91	99.78	4.65	99.59	6.38
42	99.99	1.22	99.91	2.97	99.78	4.71	99.59	6.44
44	99.98	1.28	99.91	3.02	99.77	4.76	99.58	6.50
46	99.98	1.34	99.90	3.08	99.77	4.82	99.57	6.56
48	99.98	1.40	99.90	3.14	99.76	4.88	99.56	6.61
50	99.98	1.45	99.90	3.20	99.76	4.94	99.56	6.67
52	99.98	1.51	99.89	3.26	99.75	4.99	99.55	6.73
54	99.98	1.57	99.89	3.31	99.74	5.05	99.54	6.78
56	99.97	1.63	99.89	3.37	99.74	5.11	99.53	6.84
58	99.97	1.69	99.88	3.43	99.73	5.17	99.52	6.90
60	99.97	1.74	99.88	3.49	99.73	5.23	99.51	6.96
c = 0.75 .	0.75	0.01	0.75	0.02	0.75	0.03	0.75	0.05
c = 1.00 .	1.00	0.01	1.00	0.03	1.00	0.04	1.00	0.06
c = 1.25 .	1.25	0.02	1.25	0.03	1.25	0.05	1.25	0.08

[1] From "Theory and Practice of Surveying," by Prof. J. B. Johnson. Ne York; John Wiley & Sons. We are enabled to use this form through tl courtesy of Prof. J. B. Johnson.

ABLE 137.—HORIZONTAL DISTANCES AND ELEVATIONS FROM STADIA READINGS.—*Continued*

	4°		5°		6°		7°	
Minutes	Hor. Dist.	Diff. Elev.	Hor. Dist.	Diff. Elev.	Hor. Dist.	Diff. Elev.	Hor. Dist.	Diff. Elev.
0	99.51	6.96	99.24	8.68	98.91	10.40	98.51	12.10
2	99.51	7.02	99.23	8.74	98.90	10.45	98.50	12.15
4	99.50	7.07	99.22	8.80	98.88	10.51	98.48	12.21
6	99.49	7.13	99.21	8.85	98.87	10.57	98.47	12.26
8	99.48	7.19	99.20	8.91	98.86	10.62	98.46	12.32
10	99.47	7.25	99.19	8.97	98.85	10.68	98.44	12.38
12	99.46	7.30	99.18	9.03	98.83	10.74	98.43	12.43
14	99.46	7.36	99.17	9.08	98.82	10.79	98.41	12.49
16	99.45	7.42	99.16	9.14	98.81	10.85	98.40	12.55
18	99.44	7.48	99.15	9.20	98.80	10.91	98.39	12.60
20	99.43	7.53	99.14	9.25	98.78	10.96	98.37	12.66
22	99.42	7.59	99.13	9.31	98.77	11.02	98.36	12.72
24	99.41	7.65	99.11	9.37	98.76	11.08	98.34	12.77
26	99.40	7.71	99.10	9.43	98.74	11.13	98.33	12.83
28	99.39	7.76	99.09	9.48	98.73	11.19	98.31	12.88
30	99.38	7.82	99.08	9.54	98.72	11.25	98.29	12.94
32	99.38	7.88	99.07	9.60	98.71	11.30	98.28	13.00
34	99.37	7.94	99.06	9.65	98.69	11.36	98.27	13.05
36	99.36	7.99	99.05	9.71	98.68	11.42	98.25	13.11
38	99.35	8.05	99.04	9.77	98.67	11.47	98.24	13.17
40	99.34	8.11	99.03	9.83	98.65	11.53	98.22	13.22
42	99.33	8.17	99.01	9.88	98.64	11.59	98.20	13.28
44	99.32	8.22	99.00	9.94	98.63	11.64	98.19	13.33
46	99.31	8.28	98.99	10.00	98.61	11.70	98.17	13.39
48	99.30	8.34	98.98	10.05	98.60	11.76	98.16	13.45
50	99.29	8.40	98.97	10.11	98.58	11.81	98.14	13.50
52	99.28	8.45	98.96	10.17	98.57	11.87	98.13	13.56
54	99.27	8.51	98.94	10.22	98.56	11.93	98.11	13.61
56	99.26	8.57	98.93	10.28	98.54	11.98	98.10	13.67
58	99.25	8.63	98.92	10.34	98.53	12.04	98.08	13.73
60	99.24	8.68	98.91	10.40	98.51	12.10	98.06	13.78
c = 0.75.	0.75	0.06	0.75	0.07	0.75	0.08	0.74	0.10
c = 1.00.	1.00	0.08	0.99	0.09	0.99	0.11	0.99	0.13
c = 1.25.	1.25	0.10	1.24	0.11	1.24	0.14	1.24	0.16

TABLE 137.—HORIZONTAL DISTANCES AND ELEVATIONS FRO
STADIA READINGS.—*Continued*

Minutes	8° Hor. Dist.	8° Diff. Elev.	9° Hor. Dist.	9° Diff. Elev.	10° Hor. Dist.	10° Diff. Elev.	11° Hor. Dist.	11° Diff. Elev.
0	98.06	13.78	97.55	15.45	96.98	17.10	96.36	18.73
2	98.05	13.84	97.53	15.51	96.96	17.16	96.34	18.78
4	98.03	13.89	97.52	15.56	96.94	17.21	96.32	18.84
6	98.01	13.95	97.50	15.62	96.92	17.26	96.29	18.89
8	98.00	14.01	97.48	15.67	96.90	17.32	96.27	18.95
10	97.98	14.06	97.46	15.73	96.88	17.37	96.25	19.00
12	97.97	14.12	97.44	15.78	96.86	17.43	96.23	19.05
14	97.95	14.17	97.43	15.84	96.84	17.48	96.21	19.11
16	97.93	14.23	97.41	15.89	96.82	17.54	96.18	19.16
18	97.92	14.28	97.39	15.95	96.80	17.59	96.16	19.21
20	97.90	14.34	97.37	16.00	96.78	17.65	96.14	19.27
22	97.88	14.40	97.35	16.06	96.76	17.70	96.12	19.32
24	97.87	14.45	97.33	16.11	96.74	17.76	96.09	19.38
26	97.85	14.51	97.31	16.17	96.72	17.81	96.07	19.43
28	97.83	14.56	97.29	16.22	96.70	17.86	96.05	19.48
30	97.82	14.62	97.28	16.28	96.68	17.92	96.03	19.54
32	97.80	14.67	97.26	16.33	96.66	17.97	96.00	19.59
34	97.78	14.73	97.24	16.39	96.64	18.03	95.98	19.64
36	97.76	14.79	97.22	16.44	96.62	18.08	95.96	19.70
38	97.75	14.84	97.20	16.50	96.60	18.14	95.93	19.75
40	97.73	14.90	97.18	16.55	96.57	18.19	95.91	19.80
42	97.71	14.95	97.16	16.61	96.55	18.24	95.89	19.86
44	97.69	15.01	97.14	16.66	96.53	18.30	95.86	19.91
46	97.68	15.06	97.12	16.72	96.51	18.35	95.84	19.96
48	97.66	15.12	97.10	16.77	96.49	18.41	95.82	20.02
50	97.64	15.17	97.08	16.83	96.47	18.46	95.79	20.07
52	97.62	15.23	97.06	16.88	96.45	18.51	95.77	20.12
54	97.61	15.28	97.04	16.94	96.42	18.57	95.75	20.18
56	97.59	15.34	97.02	16.99	96.40	18.62	95.72	20.23
58	97.57	15.40	97.00	17.05	96.38	18.68	95.70	20.28
60	97.55	15.45	96.98	17.10	96.36	18.73	95.68	20.34
c = 0.75.	0.74	0.11	0.74	0.12	0.74	0.14	0.73	0.15
c = 1.00.	0.99	0.15	0.99	0.16	0.98	0.18	0.98	0.20
c = 1.25.	1.23	0.18	1.23	0.21	1.23	0.23	1.22	0.25

TABLE 137.—HORIZONTAL DISTANCES AND ELEVATIONS FROM STADIA READINGS.—*Continued*

	12°		13°		14°		15°	
Minutes	Hor. Dist.	Diff. Elev.	Hor. Dist.	Diff. Elev.	Hor. Dist.	Diff. Elev.	Hor. Dist.	Diff. Elev.
0	95.68	20.34	94.94	21.92	94.15	23.47	93.30	25.00
2	95.65	20.39	94.91	21.97	94.12	23.52	93.27	25.05
4	95.63	20.44	94.89	22.02	94.09	23.58	93.24	25.10
6	95.61	20.50	94.86	22.08	94.07	23.63	93.21	25.15
8	95.58	20.55	94.84	22.13	94.04	23.68	93.18	25.20
10	95.56	20.60	94.81	22.18	94.01	23.73	93.16	25.25
12	95.53	20.66	94.79	22.23	93.98	23.78	93.13	25.30
14	95.51	20.71	94.76	22.28	93.95	23.83	93.10	25.35
16	95.49	20.76	94.73	22.34	93.93	23.88	93.07	25.40
18	95.46	20.81	94.71	22.39	93.90	23.93	93.04	25.45
20	95.44	20.87	94.68	22.44	93.87	23.99	93.01	25.50
22	95.41	20.92	94.66	22.49	93.84	24.04	92.98	25.55
24	95.39	20.97	94.63	22.54	93.81	24.09	92.95	25.60
26	95.36	21.03	94.60	22.60	93.79	24.14	92.92	25.65
28	95.34	21.08	94.58	22.65	93.76	24.19	92.89	25.70
30	95.32	21.13	94.55	22.70	93.73	24.24	92.86	25.75
32	95.29	21.18	94.52	22.75	93.70	24.29	92.83	25.80
34	95.27	21.24	94.50	22.80	93.67	24.34	92.80	25.85
36	95.24	21.29	94.47	22.85	93.65	24.39	92.77	25.90
38	95.22	21.34	94.44	22.91	93.62	24.44	92.74	25.95
40	95.19	21.39	94.42	22.96	93.59	24.49	92.71	26.00
42	95.17	21.45	94.39	23.01	93.56	24.55	92.68	26.05
44	95.14	21.50	94.36	23.06	93.53	24.60	92.65	26.10
46	95.12	21.55	94.34	23.11	93.50	24.65	92.62	26.15
48	95.09	21.60	94.31	23.16	93.47	24.70	92.59	26.20
50	95.07	21.66	94.28	23.22	93.45	24.75	92.56	26.25
52	95.04	21.71	94.26	23.27	93.42	24.80	92.53	26.30
54	95.02	21.76	94.23	23.32	93.39	24.85	92.49	26.35
56	94.99	21.81	94.20	23.37	93.36	24.90	92.46	26.40
58	94.97	21.87	94.17	23.42	93.33	24.95	92.43	26.45
60	94.94	21.92	94.15	23.47	93.30	25.00	92.40	26.50
c = 0.75 .	0.73	0.16	0.73	0.17	0.73	0.19	0.72	0.20
c = 1.00 .	0.98	0.22	0.97	0.23	0.97	0.25	0.96	0.27
c = 1.25 .	1.22	0.27	1.21	0.29	1.21	0.31	1.20	0.34

TABLE 137.—HORIZONTAL DISTANCES AND ELEVATIONS FROM STADIA READINGS.—*Continued*

Minutes	16° Hor. Dist.	16° Diff. Elev.	17° Hor. Dist.	17° Diff. Elev.	18° Hor. Dist.	18° Diff. Elev.	19° Hor. Dist.	19° Diff. Elev.
0	92.40	26.50	91.45	27.96	90.45	29.39	89.40	30.78
2	92.37	26.55	91.42	28.01	90.42	29.44	89.36	30.83
4	92.34	26.59	91.39	28.06	90.38	29.48	89.33	30.87
6	92.31	26.64	91.35	28.10	90.35	29.53	89.29	30.92
8	92.28	26.69	91.32	28.15	90.31	29.58	89.26	30.97
10	92.25	26.74	91.29	28.20	90.28	29.62	89.22	31.01
12	92.22	26.79	91.26	28.25	90.24	29.67	89.18	31.06
14	92.19	26.84	91.22	28.30	90.21	29.72	89.15	31.10
16	92.15	26.89	91.19	28.34	90.18	29.76	89.11	31.15
18	92.12	26.94	91.16	28.39	90.14	29.81	89.08	31.19
20	92.09	26.99	91.12	28.44	90.11	29.86	89.04	31.24
22	92.06	27.04	91.09	28.49	90.07	29.90	89.00	31.28
24	92.03	27.09	91.06	28.54	90.04	29.95	88.96	31.33
26	92.00	27.13	91.02	28.58	90.00	30.00	88.93	31.38
28	91.97	27.18	90.99	28.63	89.97	30.04	88.89	31.42
30	91.93	27.23	90.96	28.68	89.93	30.09	88.86	31.47
32	91.90	27.28	90.92	28.73	89.90	30.14	88.82	31.52
34	91.87	27.33	90.89	28.77	89.86	30.19	88.78	31.56
36	91.84	27.38	90.86	28.82	89.83	30.23	88.75	31.60
38	91.81	27.43	90.82	28.87	89.79	30.28	88.71	31.65
40	91.77	27.48	90.79	28.92	89.76	30.32	88.67	31.69
42	91.74	27.52	90.76	28.96	89.72	30.37	88.64	31.74
44	91.71	27.57	90.72	29.01	89.69	30.41	88.60	31.78
46	91.68	27.62	90.69	29.06	89.65	30.46	88.56	31.83
48	91.65	27.67	90.66	29.11	89.61	30.51	88.53	31.87
50	91.61	27.72	90.62	29.15	89.58	30.55	88.49	31.92
52	91.58	27.77	90.59	29.20	89.54	30.60	88.45	31.96
54	91.55	27.81	90.55	29.25	89.51	30.65	88.41	32.01
56	91.52	27.86	90.52	29.30	89.47	30.69	88.38	32.05
58	91.48	27.91	90.48	29.34	89.44	30.74	88.34	32.09
60	91.45	27.96	90.45	29.39	89.40	30.78	88.30	32.14
c = 0.75	0.72	0.21	0.72	0.23	0.71	0.24	0.71	0.25
c = 1.00	0.96	0.28	0.95	0.30	0.95	0.32	0.94	0.33
c = 1.25	1.20	0.35	1.19	0.38	1.19	0.40	1.18	0.42

TABLE 137.—HORIZONTAL DISTANCES AND ELEVATIONS FROM STADIA READINGS.—*Continued*

	20°		21°		22°		23°	
Minutes.	Hor. Dist.	Diff. Elev.	Hor. Dist.	Diff. Elev.	Hor. Dist.	Diff. Elev.	Hor. Dist.	Diff. Elev.
0	88.30	32.14	87.16	33.46	85.97	34.73	84.73	35.97
2	88.26	32.18	87.12	33.50	85.93	34.77	84.69	36.01
4	88.23	32.23	87.08	33.54	85.89	34.82	84.65	36.05
6	88.19	32.27	87.04	33.59	85.85	34.86	84.61	36.09
8	88.15	32.32	87.00	33.63	85.80	34.90	84.57	36.13
10	88.11	32.36	86.96	33.67	85.76	34.94	84.52	36.17
12	88.08	32.41	86.92	33.72	85.72	34.98	84.48	36.21
14	88.04	32.45	86.88	33.76	85.68	35.02	84.44	36.25
16	88.00	32.49	86.84	33.80	85.64	35.07	84.40	36.29
18	87.96	32.54	86.80	33.84	85.60	35.11	84.35	36.33
20	87.93	32.58	86.77	33.89	85.56	35.15	84.31	36.37
22	87.89	32.63	86.73	33.93	85.52	35.19	84.27	36.41
24	87.85	32.67	86.69	33.97	85.48	35.23	84.23	36.45
26	87.81	32.72	86.65	34.01	85.44	35.27	84.18	36.49
28	87.77	32.76	86.61	34.06	85.40	35.31	84.14	36.53
30	87.74	32.80	86.57	34.10	85.36	35.36	84.10	36.57
32	87.70	32.85	86.53	34.14	85.31	35.40	84.06	36.61
34	87.66	32.89	86.49	34.18	85.27	35.44	84.01	36.65
36	87.62	32.93	86.45	34.23	85.23	35.48	83.97	36.69
38	87.58	32.98	86.41	34.27	85.19	35.52	83.93	36.73
40	87.54	33.02	86.37	34.31	85.15	35.56	83.89	36.77
42	87.51	33.07	86.33	34.35	85.11	35.60	83.84	36.80
44	87.47	33.11	86.29	34.40	85.07	35.64	83.80	36.84
46	87.43	33.15	86.25	34.44	85.02	35.68	83.76	36.88
48	87.39	33.20	86.21	34.48	84.98	35.72	83.72	36.92
50	87.35	33.24	86.17	34.52	84.94	35.76	83.67	36.96
52	87.31	33.28	86.13	34.57	84.90	35.80	83.63	37.00
54	87.27	33.33	86.09	34.61	84.86	35.85	83.59	37.04
56	87.24	33.37	86.05	34.65	84.82	35.89	83.54	37.08
58	87.20	33.41	86.01	34.69	84.77	35.93	83.50	37.12
60	87.16	33.46	85.97	34.73	84.73	35.97	83.46	37.16
c = 0.75	0.70	0.26	0.70	0.27	0.69	0.29	0.69	0.30
c = 1.00	0.94	0.35	0.93	0.37	0.92	0.38	0.92	0.40
c = 1.25	1.17	0.44	1.16	0.46	1.15	0.48	1.15	0.50

TABLE 137.—HORIZONTAL DISTANCES AND ELEVATIONS FROM STADIA READINGS.—*Continued*

Minutes	24°		25°		26°		27°	
	Hor. Dist.	Diff. Elev.	Hor. Dist.	Diff. Elev.	Hor. Dist.	Diff Elev.	Hor. Dist.	Diff. Elev.
0	83.46	37.16	82.14	38.30	80.78	39.40	79.39	40.45
2	83.41	37.20	82.09	38.34	80.74	39.44	79.34	40.49
4	83.37	37.23	82.05	38.38	80.69	39.47	79.30	40.52
6	83.33	37.27	82.01	38.41	80.65	39.51	79.25	40.55
8	83.28	37.31	81.96	38.45	80.60	39.54	79.20	40.59
10	83.24	37.35	81.92	38.49	80.55	39.58	79.15	40.62
12	83.20	37.39	81.87	38.53	80.51	39.61	79.11	40.66
14	83.15	37.43	81.83	38.56	80.46	39.65	79.06	40.69
16	83.11	37.47	81.78	38.60	80.41	39.69	79.01	40.72
18	83.07	37.51	81.74	38.64	80.37	39.72	78.96	40.76
20	83.02	37.54	81.69	38.67	80.32	39.76	78.92	40.79
22	82.98	37.58	81.65	38.71	80.28	39.79	78.87	40.82
24	82.93	37.62	81.60	38.75	80.23	39.83	78.82	40.86
26	82.89	37.66	81.56	38.78	80.18	39.86	78.77	40.89
28	82.85	37.70	81.51	38.82	80.14	39.90	78.73	40.92
30	82.80	37.74	81.47	38.86	80.09	39.93	78.68	40.96
32	82.76	37.77	81.42	38.89	80.04	39.97	78.63	40.99
34	82.72	37.81	81.38	38.93	80.00	40.00	78.58	41.02
36	82.67	37.85	81.33	38.97	79.95	40.04	78.54	41.06
38	82.63	37.89	81.28	39.00	79.90	40.07	78.49	41.09
40	82.58	37.93	81.24	39.04	79.86	40.11	78.44	41.12
42	82.54	37.96	81.19	39.08	79.81	40.14	78.39	41.16
44	82.49	38.00	81.15	39.11	79.76	40.18	78.34	41.19
46	82.45	38.04	81.10	39.15	79.72	40.21	78.30	41.22
48	82.41	38.08	81.06	39.18	79.67	40.24	78.25	41.26
50	82.36	38.11	81.01	39.22	79.62	40.28	78.20	41.29
52	82.32	38.15	80.97	39.26	79.58	40.31	78.15	41.32
54	82.27	38.19	80.92	39.29	79.53	40.35	78.10	41.35
56	82.23	38.23	80.87	39.33	79.48	40.38	78.06	41.39
58	82.18	38.26	80.83	39.36	79.44	40.42	78.01	41.42
60	82.14	38.30	80.78	39.40	79.39	40.45	77.96	41.45
c = 0.75.	0.68	0.31	0.68	0.32	0.67	0.33	0.66	0.35
c = 1.00.	0.91	0.41	0.90	0.43	0.89	0.45	0.89	0.46
c = 1.25.	1.14	0.52	1.13	0.54	1.12	0.56	1.11	0.58

TABLE 137.—HORIZONTAL DISTANCES AND ELEVATIONS FROM STADIA READINGS.—*Concluded*

	28°		29°		30°	
Minutes	Hor. Dist.	Diff. Elev.	Hor. Dist.	Diff. Elev.	Hor. Dist.	Diff. Elev.
0	77.96	41.45	76.50	42.40	75.00	43.30
2	77.91	41.48	76.45	42.43	74.95	43.33
4	77.86	41.52	76.40	42.46	74.90	43.36
6	77.81	41.55	76.35	42.49	74.85	43.39
8	77.77	41.58	76.30	42.53	74.80	43.42
10	77.72	41.61	76.25	42.56	74.75	43.45
12	77.67	41.65	76.20	42.59	74.70	43.47
14	77.62	41.68	76.15	42.62	74.65	43.50
16	77.57	41.71	76.10	42.65	74.60	43.53
18	77.52	41.74	76.05	42.68	74.55	43.56
20	77.48	41.77	76.00	42.71	74.49	43.59
22	77.42	41.81	75.95	42.74	74.44	43.62
24	77.38	41.84	75.90	42.77	74.39	43.65
26	77.33	41.87	75.85	42.80	74.34	43.67
28	77.28	41.90	75.80	42.83	74.29	43.70
30	77.23	41.93	75.75	42.86	74.24	43.73
32	77.18	41.97	75.70	42.89	74.19	43.76
34	77.13	42.00	75.65	42.92	74.14	43.79
36	77.09	42.03	75.60	42.95	74.09	43.82
38	77.04	42.06	75.55	42.98	74.04	43.84
40	76.99	42.09	75.50	43.01	73.99	43.87
42	76.94	42.12	75.45	43.04	73.93	43.90
44	76.89	42.15	75.40	43.07	73.88	43.93
46	76.84	42.19	75.35	43.10	73.83	43.95
48	76.79	42.22	75.30	43.13	73.78	43.98
50	76.74	42.25	75.25	43.16	73.73	44.01
52	76.69	42.28	75.20	43.18	73.68	44.04
54	76.64	42.31	75.15	43.21	73.63	44.07
56	76.59	42.34	75.10	43.24	73.58	44.09
58	76.55	42.37	75.05	43.27	73.52	44.12
60	76.50	42.40	75.00	43.30	73.47	44.15
c = 0.75 ..	0.66	0.36	0.65	0.37	0.65	0.38
c = 1.00 ..	0.88	0.48	0.87	0.49	0.86	0.51
c = 1.25 ..	1.10	0.60	1.09	0.62	1.08	0.64

Diversion-line Surveys.—Where there is no doubt as to the grade to be adopted, or the alignment to be used, the location is made directly in the field and the center line is run and the cross-sections taken in the same manner as for a preliminary survey. If, however, the country is badly cut up and it is difficult to make a field location direct, a transit stadia survey is made covering the territory that will include all the possible, locations, and from the resulting contour map the different locations are projected and approximate estimates figured. The adopted line is then run in the field, cross-sections taken in the usual manner, and an accurate estimate made. This method is used so seldom that the author does not feel justified in giving much space to the theory of stadia measurements or the methods of stadia surveys (see p. 932). If the reader is not familiar with this class of work he is referred to the standard works on surveying.

A convenient scale for a contour map for the projection work mentioned above is 1″ = 20′ with a contour interval of 1 to 5′ depending on the country. Table 137 is useful for reducing stadia notes. For a small number of shots this table and a slide rule will answer the purpose; for any extended amount of work a stadia reduction diagram or Noble & Casgrain's tables are recommended.

If the stadia work is well done very satisfactory projection can be made. A reasonable closure error for stadia surveys is 5 ft. per mile horizontal distances line closure. 0.3 ft. per mile vertical elevation closure and individual contour shots 0.2 in error.

Adjustment of Instruments

Instruments must be kept in perfect adjustment and the first page of survey notes for any job should contain the signed statement of the Engineer in charge that all instruments were in good adjustment at all times.

Y-level. *To Make the Line of Collimation Parallel to the Telescope Rings.*—Level the instrument roughly. Loosen the Y-clamps so the telescope can turn freely in them; clamp the horizontal motion and by means of the leveling screws and tangent motion bring the intersection of the cross-hairs on some well-defined point. Then, without lifting from the Y's, turn the telescope over 180°, watching to see if the cross-wires remain on the point during the operation; if they do, the adjustment is correct; if they do not, correct one-half the apparent error for both vertical and horizontal wires by means of the cross-hair ring, adjusting screws, and repeat until the wires remain on the point for a complete revolution.

To Make the Longitudinal Axis of the Level Bubble Parallel to the Plane of the Line of Collimation.—Level the machine over either pair of leveling screws; unclamp the Y's; rotate the telescope in the Y's until the bubble tube is on one side of the bar. If the bubble remains in the center, the adjustment is correct. If it runs from the center bring it to its correct position by means of the sidewise adjusting screw at one end of the bubble case.

To Make the Bubble Parallel to the Rings and Line of Collimation.—Level the machine; unclamp the Y's; lift the telescope carefully from the Y's and reverse end for end; if the bubble runs to the center

fter the telescope has been reversed the adjustment is correct; not, correct one-half the error by means of the adjusting nuts on he bubble case and one-half the error with the leveling screws and epeat the test until the bubble remains in the center.

To Adjust the Y's so the Level Bubble Will Be at Right Angles to he Axis of the Instrument.—Level the machine approximately over oth sets of screws; level carefully over one set; rotate on the spindle 80°; if the bubble remains in the center the adjustment is correct; not, correct one-half the error by means of the adjusting nuts n the Ys and one-half by the leveling screws. Repeat until the ubble remains in the center when reversed over either pair of eveling screws.

To Test the Horizontal Wire.—Be sure that the pin in the Y-clamp s in the notch of the telescope ring to keep the telescope from otating; level the machine and compare the horizontal wire with ny level line; if the wire is not level loosen the cross-wire ring and urn to the correct position. Adjust again for collimation and the evel adjustments are complete.

Dumpy Level. *To Make the Bubble Perpendicular to the Axis f the Instrument.*—Level the machine roughly over both sets of eveling screws and carefully over one set; rotate on the pinion 180°; the bubble stays in the center the adjustment is correct; if not, orrect one-half the error by means of the bubble adjusting nut and ne-half by the leveling screws, and repeat until correct.

To Make the Horizontal Line of Collimation Parallel to the Level Bubble.—Level the machine; drive a stake about 150 or 200′ from nstrument and set the level rod target by the horizontal wire; rotate he instrument 180° and set another stake at the same distance rom the machine as the first one; drive it until a rod reading taken n it is the same as the reading on the first stake. These stakes will hen be level even though the machine is out of adjustment. Then et the level up near one of the stakes; level carefully and take rod eadings on both; if these readings are the same the level is in adjustment; if not, correct the position of the horizontal wire by means of he cross-wire ring screws until the readings on both stakes are the ame.

Test the horizontal wire on a level line in the same manner as for he Y-level.

Transit. *Plate Levels.*—Level the machine with each plate level ubble parallel to one set of leveling screws; rotate on the spindle 80°; if the bubbles remain the in center the adjustment is correct; not, correct one-half the error with the bubble adjusting screws nd one-half with the leveling screws. Repeat until correct.

Line of Collimation, Ordinary Distances.—Level the machine; lamp the horizontal motion; with the slow-motion screw set the ertical cross-wire on some well-defined point 500 or 600′ away; ransit the telescope and set a mark the same distance in the pposite direction; then rotate the machine on the spindle, set on he first mark, and transit the telescope; if the vertical wire strikes he second point the adjustment is correct; if not, correct one-ourth the error by means of cross-wire ring adjusting screws and epeat until correct.

To Make the Standards the Same Height.—Level the machine carefully; set the vertical wire on some well-defined point as high as can be seen; bring the telescope down and set a point; rotate the machine 180°; transit the telescope set on the low point and raise the telescope; if the wire bisects the original high point the adjustment is correct; if not, correct one-half the error by means of the standard adjusting screw.

Test the vertical wire by means of a plumb line to see that it is vertical; if not, loosen the cross-hair ring and turn to the correct position; test again for collimation.

If the transit is to be used as a level make the level bubble parallel to the horizontal wire by the two-peg method in the same manner as described for the Dumpy level.

Explanation of Curve Tables and Development of Curve Formulas.—Curves for road work need not be so carefully worked out as

FIG. 277.

in railroad surveying. Except for long curves the external i usually measured and the curve run in by the eye, and for thi reason many of the tables given in the railway field manuals ar omitted and those used are tabulated in a different form.

Table 138, *Radii of Curves.*—The curve radii are computed on : basis of 5730′ as the radius of a 1° curve and are inversely propor tional to the degree of curvature; they are tabulated to the neares 0.1′. The usual columns showing logarithm of radius, tangen offset, and middle ordinate are replaced by the deflection angl per foot of arc, per 25′ of arc, and per 50′ of arc, which saves con siderable time in the computation of deflections. These value are tabulated only for even degree, 20, 30 and 40′ curves, as ther is always sufficient leeway both in the external and tangent t select a suitable curve from this list.

Table 139, *Functions of* 1° *Curve.*—Column 1 gives the centra angle Δ for every 10′ from 0′ to 4°, every minute 4 to 100°, and ever 10′ 100 to 120°.

Column 2 gives the same central angle as in column 1 expressed in decimals of a degree. This simplifies figuring the curve length.

Columns 3 and 4 give the tangent and external for the central angles of column 1 to the nearest 0.1′. By the use of the chord lengths recommended at the top of each page of this table no correction need be made for tangent length or external distance of any desired curve, figured by dividing the value given in the table by the degree of curvature required.

The error that is introduced by the use of these chords is less than 0.1′ per 100′, which is the allowable limit of error in chaining center line.

For the convenience of readers not familiar with the theory of curves and the computation of curve notes, the following brief demonstration is made:

Radii of Curves and Degree of Curvature.—A 1° curve is defined as a curve having such a radius that 100′ of arc will subtend a 1° central angle.

There are 360° of central angle for a complete circle. The circumference of a circle is expressed by the formula $2\pi R$. Therefore the radius of 1° curve is determined by the formulas

$$2\pi R = 360 \times 100$$

$$R = \frac{36{,}000}{2\pi} = \frac{36{,}000}{2(3.14159)} = 5729.6' \qquad (1)$$

TABLE 138.—RADII AND DEFLECTIONS

Figured on a basis of $R = 5730'$ for a 1° curve.

Degree of Curve	Radius of Curve	Deflection per foot of Arc	Deflection per 25′ of Arc		Deflection per 50′ of Arc	
	Feet	Minutes	Deg.	Minutes	Deg.	Minutes
0° 30′ . .	11,460.0	00.15	—	—	0	07.5
0° 40′ . .	8.595.0	00.2	—	—	0	10.0
0° 50′ . .	6,876.0	00.25	—	—	0	12.5
1° 00′ . .	5,730.0	00.3	—	—	0	15.0
1° 20′ . .	4,297.5	00.4	—	—	0	20.0
1° 30′ . .	3,820.0	00.45	—	—	0	22.5
1° 40′ . .	3,438.0	00.5	—	—	0	25.0
2° 00′ . .	2,865.0	00.6	—	—	0	30.0
2° 20′ . .	2,455.7	00.7	—	—	0	35.0
2° 30′ . .	2,292.0	00.75	—	—	0	37.5
2° 40′ . .	2,148.8	00.8	—	—	0	40.0
3° 00′ . .	1,910.0	00.9	—	—	0	45.0

TABLE 138.—*Continued*

Degree of Curve	Radius of Curve	Deflection per foot of Arc	Deflection per 25′ of Arc		Deflection per 50′ of Arc	
	Feet	Minutes	Deg.	Minutes	Deg.	Minutes
3° 20′ . .	1,719.0	01.0	—	—	0	50.0
3° 30′ . .	1,637.1	01.05	—	—	0	52.5
3° 40′ . .	1,562.7	01.1	—	—	0	55.0
4° 00′ . .	1,432.5	01.2	—	—	1	00.0
4° 20′ . .	1,322.3	01.3	—	—	1	05.0
4° 30′ . .	1,273.3	01.35	—	—	1	07.5
4° 40′ . .	1,227.9	01.4	—	—	1	10.0
5° 00′ . .	1,146.0	01.5	—	—	1	15.0
5° 30′ . .	1,041.8	01.65	—	—	1	22.5
6° 00′ . .	955.0	01.8	—	—	1	30.0
6° 30′ .	881.5	01.95	—	—	1	37.5
7° 00′ .	818.6	02.1	—	—	1	45.0
7° 30′ . .	764.0	02.25	—	—	1	52.5
8° 00′ . .	716.3	02.4	—	—	2	00.0
8° 30′ . .	674.1	02.55	—	—	2	07.5
9° 00′ . .	636.6	02.7	—	—	2	15.0
9° 30′ . .	603.2	02.85	—	—	2	22.5
10° 00′ . .	573.0	03.0	—	—	2	30.0
10° 30′ . .	545.7	03.15	—	—	2	37.5
11° 00′ . .	520.9	03.3	—	—	2	45.0
11° 30′ . .	498.3	03.45	—	—	2	52.5
12° 00′ . .	477.5	03.6	—	—	3	00.0
12° 30′ . .	458.4	03.75	—	—	3	07.5
13° 00′ . .	440.8	03.9	—	—	3	15.0
13° 30′ . .	424.4	04.05	—	—	3	22.5
14° 00′ . .	409.3	04.2	—	—	3	30.0
14° 30′ . .	395.2	04.35	—	—	3	37.5
15° 00′ . .	382.0	04.5	—	—	3	45.0
15° 30′ . .	369.6	04.65	—	—	3	52.5
16° 00′ . .	358.1	04.8	2	00.0	4	00.0
16° 30′ . .	347.3	04.95	2	03.8	4	07.5
17° 00′ . .	337.0	05.1	2	07.5	4	15.0
17° 30′ . .	327.4	05.25	2	11.2	4	22.5
18° 00′ . .	318.3	05.4	2	15.0	4	30.0
18° 30′ . .	309.7	05.55	2	18.7	4	37.5

TABLE 138.—*Continued*

Degree of Curve	Radius of Curve	Deflection per ft. of Arc	Deflection per 25′ of Arc		Deflection per 50′ of Arc	
		Minutes	Degree	Minutes		
19° 00′	301.6	05.7	2	22.5		
19° 30′	293.8	05.85	2	26.2		
20° 00′	286.5	06.0	2	30.0		
20° 30′	279.5	06.15	2	33.7		
21° 00′	272.9	06.30	2	37.5		
21° 30′	266.5	06.45	2	41.2		
22° 00′	260.5	06.6	2	45.0		
22° 30′	254.7	06.75	2	48.7		
23° 00′	249.1	06.9	2	52.5		
23° 30′	243.8	07.05	2	56.2		
24° 00′	238.8	07.2	3	00.0		
24° 30′	233.9	07.35	3	03.7		
25° 00′	229.2	07.5	3	07.5		
26° 00′	220.4	07.8	3	15.0		
27° 00′	212.2	08.1	3	22.5		
28° 00′	204.6	08.4	3	30.0		
29° 00′	197.6	08.7	3	37.5		
30° 00′	191.0	09.0	3	45.0	Deflection per 10′ of Arc	
31° 00′	184.8	09.3	3	52.5		
32° 00′	179.1	09.6	4	00.0	1°	36′
33° 00′	173.6	09.9	—	—	1°	39′
34° 00′	168.5	10.2	—	—	1°	42′
35° 00′	163.7	10.5	—	—	1°	45′
36° 00′	159.2	10.8	—	—	1°	48′
37° 00′	154.9	11.1	—	—	1°	51′
38° 00′	150.8	11.4	—	—	1°	54′
39° 00′	146.9	11.7	—	—	1°	57′
40° 00′	143.2	12.0	—	—	2°	00′
42° 00′	136.4	12.6	—	—	2°	06′
44° 00′	130.2	13.2	—	—	2°	12′
46° 00′	124.6	13.8	—	—	2°	18′
48° 00′	119.4	14.4	—	—	2°	24′
50° 00′	114.6	15.0	—	—	2°	30′
52° 00′	110.2	15.6	—	—	2°	36′
54° 00′	106.1	16.2	—	—	2°	42′
56° 00′	102.3	16.8	—	—	2°	48′

For all practical purposes the value of 5730 can be used.

In the same manner a 2° curve is one having such a radius that 100′ of arc will subtend 2° of central angle, and its radius is

$$2\pi R = \frac{360}{2} \times 100$$

$$R = \frac{18,000}{2\pi},$$

or one-half of the radius of a 1° curve. The radius of a 3° curve will be one-third of 5730. The radius of a 4° curve will be one-fourth of 5730.

The formula for the radius of any degree of curve is, therefore

$$R = \frac{5730}{D}. \quad (2$$

The degree of curvature for any specified radius is, therefore,

$$D = \frac{5730}{R}. \quad (3$$

In general, the degree of curvature is expressed by the central angle subtended by 100′ of arc, and the radius for that degree of curve is found by dividing 5730′, the radius of a 1° curve, by the degree of curve desired expressed in degrees and decimals of a degree; that is, if the radius of a 3° 30′ curve is wanted, divide 5730 by 3.5, which equals 1637.1′. The radii given in Table 13 are computed in this manner.

Length of Curve.—For a 5° curve a central angle of 5° subtends 100′ of arc; a central angle of 10°, 200′ of arc; a central angle of 12° 30′, 250′ or arc; that is, for a specified central angle the length of any specified curve equals that central angle expressed in degrees and decimals of a degree divided by the degree of curve expressed in degrees and decimals multiplied by 100; *i.e.*, the length of a 10° 15′ curve for a central angle of 20° 45′ $= \frac{20.75}{10.25} \times 100' = 202.4$ and is expressed by the formula (continued on p. 885).

TABLE 139.—FUNCTIONS OF A 1° CURVE FIGURED ON A BASIS OF $R = 5730'$ AND TABULATED TO TENTHS OF FEET

Use 100′ chords up to 8° Curves
Use 50′ chords up to 16° Curves
Use 25′ chords up to 32° Curves
Use 10′ chords above 32° Curves

Minutes	0°		1°		2°		3°		Minutes
	Ext.	Tan.	Ext.	Tan.	Ext.	Tan.	Ext.	Tan.	
0	0.0	0.0	0.2	50.0	0.9	100.0	2.0	150.1	0
10	0.0	8.3	0.3	58.3	1.0	108.4	2.2	158.4	10
20	0.0	16.7	0.4	66.7	1.2	116.7	2.4	166.8	20
30	0.1	25.0	0.5	75.0	1.4	125.0	2.7	175.1	30
40	0.1	33.3	0.6	83.3	1.6	133.4	2.9	183.4	40
50	0.2	41.7	0.7	91.7	1.8	141.7	3.2	191.7	50
60	0.2	50.0	0.9	100.0	2.0	150.1	3.5	200.1	60

Use 100′ chords up to 8° Curves
Use 50′ chords up to 16° Curves
Use 25′ chords up to 32° Curves
Use 10′ chords above 32° Curves

Minutes	Dec. of Degree	4° Ext.	4° Tan.	5° Ext.	5° Tan.	6° Ext.	6° Tan.	7° Ext.	7° Tan.	Minutes
0	.0000	3.5	200.1	5.5	250.2	7.9	300.3	10.7	350.4	0
1	.0167	3.5	200.9	5.5	251.0	7.9	301.1	10.8	351.3	1
2	.0333	3.6	201.8	5.5	251.8	8.0	302.0	10.8	352.1	2
3	.0500	3.6	202.6	5.6	252.7	8.0	302.8	10.9	352.9	3
4	.0667	3.6	203.4	5.6	253.5	8.0	303.6	10.9	353.8	4
5	.0833	3.6	204.3	5.6	254.3	8.1	304.5	11.0	354.6	5
6	.1000	3.7	205.1	5.7	255.2	8.1	305.3	11.0	355.5	6
7	.1167	3.7	205.9	5.7	256.0	8.2	306.1	11.1	356.3	7
8	.1333	3.7	206.8	5.8	256.8	8.2	307.0	11.1	357.1	8
9	.1500	3.8	207.6	5.8	257.7	8.3	307.8	11.2	358.0	9
10	.1667	3.8	208.4	5.8	258.5	8.3	308.6	11.2	358.8	10
11	.1833	3.8	209.3	5.9	259.3	8.4	309.5	11.3	359.6	11
12	.2000	3.9	210.1	5.9	260.2	8.4	310.3	11.3	360.5	12
13	.2167	3.9	210.9	5.9	261.0	8.4	311.1	11.4	361.3	13
14	.2333	3.9	211.8	6.0	261.9	8.5	312.0	11.4	362.2	14
15	.2500	3.9	212.6	6.0	262.7	8.5	312.8	11.5	363.0	15
16	.2667	4.0	213.4	6.1	263.5	8.6	313.7	11.5	363.8	16
17	.2833	4.0	214.3	6.1	264.4	8.6	314.5	11.6	364.7	17
18	.3000	4.0	215.1	6.1	265.2	8.7	315.3	11.7	365.5	18
19	.3167	4.1	215.9	6.2	266.0	8.7	316.2	11.7	366.3	19
20	.3333	4.1	216.8	6.2	266.9	8.8	317.0	11.8	367.2	20
21	.3500	4.1	217.6	6.2	267.7	8.8	317.8	11.8	368.0	21
22	.3667	4.2	218.4	6.3	268.5	8.9	318.7	11.9	368.8	22
23	.3833	4.2	219.3	6.3	269.4	8.9	319.5	11.9	369.7	23
24	.4000	4.2	220.1	6.4	270.2	9.0	320.3	12.0	370.5	24
25	.4167	4.3	220.9	6.4	271.0	9.0	321.2	12.0	371.4	25
26	.4333	4.3	221.8	6.4	271.9	9.0	322.0	12.1	372.2	26
27	.4500	4.3	222.6	6.5	272.7	9.1	322.8	12.1	373.0	27
28	.4667	4.4	223.5	6.5	273.5	9.1	323.7	12.2	373.9	28
29	.4833	4.4	224.3	6.5	274.4	9.2	324.5	12.2	374.7	29
30	.5000	4.4	225.1	6.6	275.2	9.2	325.4	12.3	375.5	30
31	.5167	4.5	226.0	6.6	276.1	9.3	326.2	12.4	376.4	31
32	.5333	4.5	226.8	6.7	276.9	9.3	327.0	12.4	377.2	32
33	.5500	4.5	227.6	6.7	277.7	9.4	327.9	12.5	378.1	33
34	.5667	4.6	228.5	6.8	278.6	9.4	328.7	12.5	378.9	34
35	.5833	4.6	229.3	6.8	279.4	9.5	329.5	12.6	379.7	35
36	.6000	4.6	230.1	6.8	280.2	9.5	330.4	12.6	380.6	36
37	.6167	4.7	231.0	6.9	281.1	9.6	331.2	12.7	381.4	37
38	.6333	4.7	231.8	6.9	281.9	9.6	332.0	12.7	382.2	38
39	.6500	4.7	232.6	7.0	282.7	9.7	332.9	12.8	383.1	39
40	.6667	4.8	233.5	7.0	283.6	9.7	333.7	12.9	383.9	40
41	.6833	4.8	234.3	7.1	284.4	9.8	334.6	12.9	384.7	41
42	.7000	4.8	235.1	7.1	285.2	9.8	335.4	13.0	385.6	42
43	.7167	4.9	236.0	7.1	286.1	9.9	336.2	13.0	386.4	43
44	.7333	4.9	236.8	7.2	286.9	9.9	337.1	13.1	387.3	44
45	.7500	4.9	237.6	7.2	287.7	10.0	337.9	13.1	388.1	45
46	.7667	5.0	238.5	7.3	288.6	10.0	338.7	13.2	388.9	46
47	.7833	5.0	239.3	7.3	289.4	10.1	339.6	13.2	389.8	47
48	.8000	5.0	240.1	7.3	290.3	10.1	340.4	13.3	390.6	48
49	.8167	5.1	241.0	7.4	291.1	10.2	341.2	13.4	391.4	49
50	.8333	5.1	241.8	7.4	291.9	10.2	342.1	13.4	392.3	50
51	.8500	5.1	242.6	7.5	292.8	10.3	342.9	13.5	393.1	51
52	.8667	5.2	243.5	7.5	293.6	10.3	343.7	13.5	394.0	52
53	.8833	5.2	244.3	7.5	294.4	10.4	344.6	13.6	394.8	53
54	.9000	5.2	245.2	7.6	295.3	10.4	345.4	13.7	395.6	54
55	.9167	5.3	246.0	7.6	296.1	10.5	346.3	13.7	396.5	55
56	.9333	5.3	246.8	7.7	296.9	10.5	347.1	13.8	397.3	56
57	.9500	5.3	247.7	7.7	297.8	10.6	347.9	13.8	398.1	57
58	.9667	5.4	248.5	7.8	298.6	10.6	348.8	13.9	399.0	58
59	.9833	5.4	249.3	7.8	299.4	10.7	349.6	13.9	399.8	59

Use 100′ Chords up to 8° Curves Use 25′ Chords up to 32° Curves
Use 50′ Chords up to 16° Curves Use 10′ Chords above 32° Curves

Minutes	Dec. of Degree	8°		9°		10°		11°		Minutes
		Ext.	Tan.	Ext.	Tan.	Ext.	Tan.	Ext.	Tan.	
0	.0000	14.0	400.7	17.7	450.9	21.9	501.3	26.5	551.7	0
1	.0167	14.0	401.5	17.8	451.8	21.9	502.2	26.6	552.6	1
2	.0333	14.1	402.4	17.8	452.6	22.0	503.0	26.7	553.4	2
3	.0500	14.2	403.2	17.9	453.4	22.1	503.8	26.7	554.3	3
4	.0667	14.2	404.0	18.0	454.3	22.2	504.7	26.8	555.1	4
5	.0833	14.3	404.8	18.0	455.1	22.3	505.5	26.9	555.9	5
6	.1000	14.3	405.7	18.1	456.0	22.3	506.4	27.0	556.8	6
7	.1167	14.4	406.5	18.2	456.8	22.4	507.2	27.1	557.6	7
8	.1333	14.5	407.4	18.3	457.7	22.5	508.0	27.2	558.5	8
9	.1500	14.5	408.2	18.3	458.5	22.6	508.9	27.2	559.3	9
10	.1667	14.6	409.0	18.4	459.3	22.6	509.7	27.3	560.1	10
11	.1833	14.6	409.9	18.4	460.2	22.7	510.6	27.4	561.0	11
12	.2000	14.7	410.7	18.5	461.0	22.8	511.4	27.5	561.8	12
13	.2167	14.8	411.5	18.6	461.8	22.9	512.2	27.6	562.7	13
14	.2333	14.8	412.4	18.7	462.7	22.9	513.1	27.7	563.5	14
15	.2500	14.9	413.2	18.7	463.5	23.0	513.9	27.7	564.3	15
16	.2667	14.9	414.1	18.8	464.4	23.1	514.8	27.8	565.2	16
17	.2833	15.0	414.9	18.9	465.2	23.2	515.6	27.9	566.0	17
18	.3000	15.1	415.7	18.9	466.0	23.2	516.4	28.0	566.9	18
19	.3167	15.1	416.6	19.0	466.9	23.3	517.3	28.1	567.7	19
20	.3333	15.2	417.4	19.1	467.7	23.4	518.1	28.1	568.5	20
21	.3500	15.2	418.2	19.1	468.5	23.5	519.0	28.2	569.4	21
22	.3667	15.3	419.1	19.2	469.4	23.5	519.8	28.3	570.2	22
23	.3833	15.4	419.9	19.3	470.2	23.6	520.6	28.4	571.1	23
24	.4000	15.4	420.8	19.3	471.1	23.7	521.5	28.5	571.9	24
25	.4167	15.5	421.6	19.4	471.9	23.8	522.3	28.6	572.8	25
26	.4333	15.6	422.4	19.5	472.8	23.8	523.2	28.6	573.6	26
27	.4500	15.6	423.3	19.5	473.6	23.9	524.0	28.7	574.4	27
28	.4667	15.7	424.1	19.6	474.4	24.0	524.9	28.8	575.3	28
29	.4833	15.7	424.9	19.7	475.3	24.1	525.7	28.9	576.1	29
30	.5000	15.8	425.8	19.8	476.1	24.1	526.5	29.0	577.0	30
31	.5167	15.9	426.6	19.8	476.9	24.2	527.4	29.1	577.8	31
32	.5333	15.9	427.5	19.9	477.8	24.3	528.2	29.1	578.6	32
33	.5500	16.0	428.3	20.0	478.6	24.4	529.0	29.2	579.5	33
34	.5667	16.0	429.1	20.0	479.5	24.5	529.9	29.3	580.3	34
35	.5833	16.1	430.0	20.1	480.3	24.5	530.7	29.4	581.2	35
36	.6000	16.2	430.8	20.2	481.1	24.6	531.6	29.5	582.0	36
37	.6167	16.2	431.7	20.2	482.0	24.7	532.4	29.6	582.8	37
38	.6333	16.3	432.5	20.3	482.8	24.8	533.3	29.7	583.7	38
39	.6500	16.4	433.3	20.4	483.6	24.8	534.1	29.7	584.5	39
40	.6667	16.4	434.2	20.5	484.5	24.9	534.9	29.8	585.4	40
41	.6833	16.5	435.0	20.5	485.3	25.0	535.8	29.9	586.2	41
42	.7000	16.6	435.9	20.6	486.2	25.1	536.6	30.0	587.1	42
43	.7167	16.6	436.7	20.7	487.0	25.1	537.5	30.1	587.9	43
44	.7333	16.7	437.5	20.7	487.9	25.2	538.3	30.2	588.7	44
45	.7500	16.7	438.4	20.8	488.7	25.3	539.1	30.3	589.6	45
46	.7667	16.8	439.2	20.9	489.6	25.4	540.0	30.3	590.4	46
47	.7833	16.9	440.0	21.0	490.4	25.5	540.8	30.4	591.3	47
48	.8000	16.9	440.9	21.0	491.2	25.5	541.7	30.5	592.1	48
49	.8167	17.0	441.7	21.1	492.0	25.6	542.5	30.6	592.9	49
50	.8333	17.1	442.5	21.2	492.9	25.7	543.3	30.7	593.8	50
51	.8500	17.1	443.4	21.2	493.7	25.8	544.2	30.8	594.6	51
52	.8667	17.2	444.2	21.3	494.6	25.9	545.0	30.9	595.5	52
53	.8833	17.3	445.1	21.4	495.4	25.9	545.9	31.0	596.3	53
54	.9000	17.3	445.9	21.5	496.3	26.0	546.7	31.0	597.2	54
55	.9167	17.4	446.7	21.5	497.1	26.1	547.5	31.1	598.0	55
56	.9333	17.5	447.6	21.6	498.0	26.2	548.4	31.2	598.8	56
57	.9500	17.5	448.4	21.7	498.8	26.3	549.2	31.3	599.7	57
58	.9667	17.6	449.3	21.8	499.6	26.3	550.1	31.4	600.5	58
59	.9833	17.6	450.1	21.8	500.4	26.4	550.9	31.5	601.4	59

Use 100′ Chords up to 8° Curves Use 25′ Chords up to 32° Curves
Use 50′ Chords up to 16° Curves Use 10′ Chords above 32° Curves

Minutes	Dec. of Degree	12° Ext.	12° Tan.	13° Ext.	13° Tan.	14° Ext.	14° Tan.	15° Ext.	15° Tan.	Minutes
0	.0000	31.6	602.2	37.1	652.9	43.0	703.5	49.4	754.4	0
1	.0167	31.7	603.1	37.2	653.7	43.1	704.4	49.6	755.2	1
2	.0333	31.7	603.9	37.3	654.6	43.2	705.2	49.7	756.1	2
3	.0500	31.8	604.7	37.4	655.4	43.3	706.1	49.8	756.9	3
4	.0667	31.9	605.6	37.5	656.3	43.4	706.9	49.9	757.7	4
5	.0833	32.0	606.4	37.6	657.1	43.5	707.8	50.0	758.6	5
6	.1000	32.1	607.3	37.7	657.9	43.7	708.6	50.1	759.4	6
7	.1167	32.2	608.1	37.7	658.8	43.8	709.5	50.2	760.3	7
8	.1333	32.3	609.0	37.8	659.6	43.9	710.3	50.3	761.1	8
9	.1500	32.4	609.8	37.9	660.5	44.0	711.2	50.5	762.0	9
10	.1667	32.5	610.7	38.0	661.3	44.1	712.0	50.6	762.8	10
11	.1833	32.5	611.5	38.1	662.2	44.2	712.9	50.7	763.7	11
12	.2000	32.6	612.4	38.2	663.0	44.3	713.7	50.8	764.5	12
13	.2167	32.7	613.2	38.3	663.8	44.4	714.6	50.9	765.4	13
14	.2333	32.8	614.0	38.4	664.7	44.5	715.4	51.0	766.2	14
15	.2500	32.9	614.9	38.5	665.5	44.6	716.3	51.1	767.1	15
16	.2667	33.0	615.7	38.6	666.4	44.7	717.1	51.2	767.9	16
17	.2833	33.1	616.6	38.7	667.2	44.8	718.0	51.3	768.8	17
18	.3000	33.2	617.4	38.8	668.1	44.9	718.8	51.5	769.6	18
19	.3167	33.3	618.3	38.9	668.9	45.0	719.6	51.6	770.5	19
20	.3333	33.4	619.1	39.0	669.8	45.1	720.5	51.7	771.3	20
21	.3500	33.4	619.9	39.1	670.6	45.2	721.3	51.8	772.2	21
22	.3667	33.5	620.8	39.2	671.4	45.3	722.2	51.9	773.0	22
23	.3833	33.6	621.6	39.3	672.3	45.4	723.1	52.0	773.9	23
24	.4000	33.7	622.5	39.4	673.1	45.5	723.9	52.1	774.7	24
25	.4167	33.8	623.3	39.5	674.0	45.6	724.7	52.3	775.6	25
26	.4333	33.9	624.2	39.6	674.8	45.8	725.6	52.4	776.4	26
27	.4500	34.0	625.0	39.7	675.7	45.9	726.5	52.5	777.3	27
28	.4667	34.1	625.9	39.8	676.5	46.0	727.3	52.6	778.1	28
29	.4833	34.2	626.7	39.9	677.4	46.1	728.1	52.7	778.9	29
30	.5000	34.3	627.6	40.0	678.2	46.2	729.0	52.8	779.8	30
31	.5167	34.4	628.4	40.1	679.0	46.3	729.8	52.9	780.6	31
32	.5333	34.5	629.2	40.2	679.9	46.4	730.7	53.1	781.5	32
33	.5500	34.5	630.1	40.3	680.7	46.5	731.5	53.2	782.3	33
34	.5667	34.6	630.9	40.4	681.6	46.6	732.4	53.3	783.2	34
35	.5833	34.7	631.8	40.5	682.4	46.7	733.2	53.4	784.0	35
36	.6000	34.8	632.6	40.6	683.3	46.8	734.0	53.5	784.9	36
37	.6167	34.9	633.5	40.7	684.1	46.9	734.9	53.6	785.7	37
38	.6333	35.0	634.3	40.8	685.0	47.0	735.7	53.7	786.6	38
39	.6500	35.1	635.1	40.9	685.8	47.2	736.6	53.9	787.4	39
40	.6667	35.2	636.0	41.0	686.6	47.3	737.4	54.0	788.3	40
41	.6833	35.3	636.8	41.1	687.5	47.4	738.3	54.1	789.1	41
42	.7000	35.4	637.7	41.2	688.3	47.5	739.1	54.2	790.0	42
43	.7167	35.5	638.5	41.3	689.2	47.6	740.0	54.3	790.8	43
44	.7333	35.6	639.4	41.4	690.0	47.7	740.8	54.4	791.7	44
45	.7500	35.7	640.2	41.5	690.9	47.8	741.7	54.6	792.5	45
46	.7667	35.8	641.1	41.6	691.7	47.9	742.5	54.7	793.4	46
47	.7833	35.8	641.9	41.7	692.5	48.0	743.4	54.8	794.2	47
48	.8000	35.9	642.7	41.8	693.4	48.1	744.2	54.9	795.1	48
49	.8167	36.0	643.6	41.9	694.2	48.2	745.1	55.0	795.9	49
50	.8333	36.1	644.4	42.0	695.1	48.3	745.9	55.1	796.8	50
51	.8500	36.2	645.3	42.1	695.9	48.5	746.7	55.3	797.6	51
52	.8667	36.3	646.1	42.2	696.8	48.6	747.6	55.4	798.5	52
53	.8833	36.4	647.0	42.3	697.6	48.7	748.4	55.5	799.3	53
54	.9000	36.5	647.8	42.4	698.5	48.8	749.3	55.6	800.2	54
55	.9167	36.6	648.6	42.5	699.3	48.9	750.1	55.7	801.0	55
56	.9333	36.7	649.5	42.6	700.1	49.0	751.0	55.8	801.9	56
57	.9500	36.8	650.3	42.7	701.0	49.1	751.8	56.0	802.7	57
58	.9667	36.9	651.2	42.8	701.8	49.2	752.7	56.1	803.6	58
59	.9833	37.0	652.0	42.9	702.7	49.3	753.5	56.2	804.4	59

Use 100′ Chords up to 8° Curves
Use 50′ Chords up to 16° Curves
Use 25′ Chords up to 32° Curves
Use 10′ Chords above 32° Curves

Minutes	Dec. of Degree	16°		17°		18°		19°		Minutes
		Ext.	Tan.	Ext.	Tan.	Ext.	Tan.	Ext.	Tan.	
0	.0000	56.3	805.3	63.6	856.4	71.4	907.5	79.7	958.9	0
1	.0167	56.4	806.2	63.8	857.2	71.6	908.4	79.8	959.7	1
2	.0333	56.5	807.0	63.9	858.1	71.7	909.2	79.9	960.6	2
3	.0500	56.7	807.8	64.0	858.9	71.8	910.1	80.1	961.4	3
4	.0667	56.8	808.6	64.2	859.8	72.0	910.9	80.2	962.3	4
5	.0833	56.9	809.5	64.3	860.6	72.1	911.8	80.4	963.2	5
6	.1000	57.0	810.4	64.4	861.5	72.2	912.7	80.5	964.0	6
7	.1167	57.1	811.2	64.5	862.3	72.4	913.5	80.7	964.9	7
8	.1333	57.3	812.1	64.7	863.2	72.5	914.4	80.8	965.7	8
9	.1500	57.4	812.9	64.8	864.0	72.6	915.2	80.9	966.6	9
10	.1667	57.5	813.8	64.9	864.9	72.8	916.1	81.1	967.4	10
11	.1833	57.6	814.6	65.0	865.7	72.9	916.9	81.2	968.3	11
12	.2000	57.7	815.5	65.2	866.6	73.0	917.8	81.4	969.2	12
13	.2167	57.9	816.3	65.3	867.4	73.2	918.6	81.5	970.0	13
14	.2333	58.0	817.2	65.4	868.3	73.3	919.5	81.7	970.9	14
15	.2500	58.1	818.0	65.6	869.1	73.4	920.3	81.8	971.7	15
16	.2667	58.2	818.9	65.7	870.0	73.6	921.2	81.9	972.6	16
17	.2833	58.3	819.7	65.8	870.8	73.7	922.0	82.1	973.4	17
18	.3000	58.5	820.6	65.9	871.7	73.9	922.9	82.2	974.3	18
19	.3167	58.6	821.4	66.1	872.5	74.0	923.8	82.4	975.1	19
20	.3333	58.7	822.3	66.2	873.4	74.1	924.6	82.5	976.0	20
21	.3500	58.8	823.1	66.3	874.2	74.3	925.5	82.7	976.9	21
22	.3667	58.9	824.0	66.4	875.1	74.4	926.3	82.8	977.7	22
23	.3833	59.1	824.8	66.6	875.9	74.5	927.2	82.9	978.6	23
24	.4000	59.2	825.7	66.7	876.8	74.7	928.1	83.1	979.4	24
25	.4167	59.3	826.5	66.8	877.6	74.8	928.9	83.2	980.3	25
26	.4333	59.4	827.4	67.0	878.5	74.9	929.8	83.4	981.2	26
27	.4500	59.6	828.2	67.1	879.3	75.1	930.6	83.5	982.0	27
28	.4667	59.7	829.1	67.2	880.2	75.2	931.5	83.7	982.9	28
29	.4833	59.8	829.9	67.3	881.0	75.4	932.3	83.8	983.7	29
30	.5000	59.9	830.8	67.5	881.9	75.5	933.2	84.0	984.6	30
31	.5167	60.0	831.6	67.6	882.7	75.6	934.0	84.1	985.4	31
32	.5333	60.2	832.5	67.7	883.6	75.8	934.9	84.3	986.3	32
33	.5500	60.3	833.3	67.9	884.5	75.9	935.7	84.4	987.2	33
34	.5667	60.4	834.2	68.0	885.3	76.1	936.6	84.6	988.0	34
35	.5833	60.5	835.1	68.1	886.2	76.2	937.5	84.7	988.9	35
36	.6000	60.7	835.9	68.2	887.0	76.3	938.3	84.8	989.7	36
37	.6167	60.8	836.8	68.4	887.9	76.5	939.2	85.0	990.6	37
38	.6333	60.9	837.6	68.5	888.7	76.6	940.0	85.1	991.5	38
39	.6500	61.0	838.5	68.6	889.6	76.7	940.9	85.3	992.3	39
40	.6667	61.1	839.3	68.8	890.4	76.9	941.7	85.4	993.2	40
41	.6833	61.3	840.2	68.9	891.3	77.0	942.6	85.6	994.0	41
42	.7000	61.4	841.0	69.0	892.2	77.1	943.5	85.7	994.9	42
43	.7167	61.5	841.9	69.2	893.0	77.3	944.3	85.9	995.8	43
44	.7333	61.6	842.7	69.3	893.9	77.4	945.2	86.0	996.6	44
45	.7500	61.8	843.6	69.4	894.7	77.6	946.0	86.2	997.5	45
46	.7667	61.9	844.4	69.6	895.6	77.7	946.9	86.3	998.3	46
47	.7833	62.0	845.3	69.7	896.4	77.8	947.7	86.5	999.2	47
48	.8000	62.1	846.1	69.8	897.3	78.0	948.6	86.6	1000.0	48
49	.8167	62.3	847.0	70.0	898.1	78.1	949.4	86.8	1000.9	49
50	.8333	62.4	847.8	70.1	899.0	78.3	950.3	86.9	1001.8	50
51	.8500	62.5	848.7	70.2	899.8	78.4	951.1	87.1	1002.6	51
52	.8667	62.6	849.5	70.4	900.7	78.5	952.0	87.2	1003.5	52
53	.8833	62.8	850.4	70.5	901.5	78.7	952.9	87.4	1004.3	53
54	.9000	62.9	851.2	70.6	902.4	78.8	953.7	87.5	1005.2	54
55	.9167	63.0	852.1	70.8	903.3	79.0	954.6	87.7	1006.0	55
56	.9333	63.1	852.9	70.9	904.1	79.1	955.4	87.8	1006.9	56
57	.9500	63.3	853.8	71.0	905.0	79.2	956.3	88.0	1007.7	57
58	.9667	63.4	854.7	71.2	905.8	79.4	957.2	88.1	1008.6	58
59	.9833	63.5	855.5	71.3	906.7	79.5	958.0	88.2	1069.5	59

Use 100′ Chords up to 8° Curves
Use 50′ Chords up to 16° Curves
Use 25′ Chords up to 32° Curves
Use 10′ Chords above 32° Curves

Minutes	Dec. of Degree	20° Ext.	20° Tan.	21° Ext.	21° Tan.	22° Ext.	22° Tan.	23° Ext.	23° Tan.	Minutes
0	.0000	88.4	1010.4	97.6	1062.0	107.2	1113.8	117.4	1165.8	0
1	.0167	88.5	1011.2	97.7	1062.8	107.4	1114.6	117.6	1166.6	1
2	.0333	88.7	1012.1	97.9	1063.7	107.6	1115.5	117.7	1167.5	2
3	.0500	88.8	1012.9	98.1	1064.5	107.7	1116.4	117.9	1168.3	3
4	.0667	89.0	1013.8	98.2	1065.4	107.9	1117.3	118.1	1169.2	4
5	.0833	89.1	1014.6	98.4	1066.3	108.0	1118.1	118.3	1170.1	5
6	.1000	89.3	1015.5	98.5	1067.2	108.2	1119.0	118.4	1171.0	6
7	.1167	89.4	1016.3	98.7	1068.0	108.4	1119.8	118.6	1171.8	7
8	.1333	89.6	1017.2	98.8	1068.9	108.6	1120.7	118.8	1172.7	8
9	.1500	89.7	1018.1	99.0	1069.7	108.7	1121.5	118.9	1173.5	9
10	.1667	89.9	1019.0	99.2	1070.6	108.9	1122.4	119.1	1174.4	10
11	.1833	90.0	1019.8	99.3	1071.5	109.0	1123.3	119.3	1175.3	11
12	.2000	90.2	1020.7	99.5	1072.4	109.2	1124.2	119.5	1176.2	12
13	.2167	90.3	1021.5	99.6	1073.2	109.4	1125.0	119.7	1177.0	13
14	.2333	90.5	1022.4	99.8	1074.1	109.6	1125.9	119.8	1177.9	14
15	.2500	90.6	1023.2	99.9	1074.9	109.7	1126.7	120.0	1178.8	15
16	.2667	90.8	1024.1	100.1	1075.8	109.9	1127.6	120.2	1179.7	16
17	.2833	90.9	1024.9	100.2	1076.6	110.0	1128.5	120.4	1180.5	17
18	.3000	91.1	1025.8	100.4	1077.5	110.2	1129.4	120.5	1181.4	18
19	.3167	91.2	1026.7	100.5	1078.4	110.4	1130.2	120.7	1182.2	19
20	.3333	91.4	1027.6	100.7	1079.3	110.6	1131.1	120.9	1183.1	20
21	.3500	91.6	1028.4	100.9	1080.1	110.7	1131.9	121.0	1184.0	21
22	.3667	91.7	1029.3	101.1	1081.0	110.9	1132.8	121.2	1184.9	22
23	.3833	91.9	1030.1	101.2	1081.8	111.0	1133.7	121.4	1185.7	23
24	.4000	92.0	1031.0	101.4	1082.7	111.2	1134.6	121.6	1186.6	24
25	.4167	92.2	1031.8	101.5	1083.5	111.4	1135.4	121.7	1187.5	25
26	.4333	92.3	1032.7	101.7	1084.4	111.6	1136.3	121.9	1188.4	26
27	.4500	92.5	1033.5	101.8	1085.3	111.7	1137.1	122.1	1189.2	27
28	.4667	92.6	1034.4	102.0	1086.2	111.9	1138.0	122.3	1190.1	28
29	.4833	92.8	1035.2	102.1	1087.0	112.1	1138.8	122.4	1190.9	29
30	.5000	92.9	1036.1	102.3	1087.9	112.3	1139.7	122.6	1191.8	30
31	.5167	93.1	1037.0	102.5	1088.7	112.4	1140.6	122.8	1192.7	31
32	.5333	93.2	1037.9	102.7	1089.6	112.6	1141.5	123.0	1193.6	32
33	.5500	93.4	1038.7	102.8	1090.4	112.7	1142.3	123.2	1194.4	33
34	.5667	93.5	1039.6	103.0	1091.3	112.9	1143.2	123.3	1195.3	34
35	.5833	93.7	1040.4	103.1	1092.2	113.1	1144.0	123.5	1196.2	35
36	.6000	93.9	1041.3	103.3	1093.1	113.3	1144.9	123.7	1197.1	36
37	.6167	94.0	1042.1	103.4	1093.9	113.4	1145.8	123.9	1197.9	37
38	.6333	94.2	1043.0	103.6	1094.8	113.6	1146.7	124.1	1198.8	38
39	.6500	94.3	1043.9	103.8	1095.6	113.7	1147.5	124.3	1199.6	39
40	.6667	94.5	1044.8	104.0	1096.5	113.9	1148.4	124.4	1200.5	40
41	.6833	94.6	1045.6	104.1	1097.4	114.1	1149.2	124.6	1201.4	41
42	.7000	94.8	1046.5	104.3	1098.3	114.3	1150.1	124.8	1202.3	42
43	.7167	94.9	1047.3	104.4	1099.1	114.4	1151.0	124.9	1203.1	43
44	.7333	95.1	1048.2	104.6	1100.0	114.6	1151.9	125.1	1204.0	44
45	.7500	95.2	1049.0	104.7	1100.8	114.8	1152.7	125.3	1204.9	45
46	.7667	95.4	1049.9	104.9	1101.7	115.0	1153.6	125.5	1205.8	46
47	.7833	95.6	1050.8	105.1	1102.5	115.2	1154.5	125.7	1206.7	47
48	.8000	95.7	1051.7	105.3	1103.4	115.3	1155.4	125.8	1207.5	48
49	.8167	95.9	1052.5	105.4	1104.3	115.5	1156.2	126.0	1208.3	49
50	.8333	96.0	1053.4	105.6	1105.2	115.7	1157.1	126.2	1209.2	50
51	.8500	96.2	1054.2	105.7	1106.0	115.8	1157.9	126.4	1210.1	51
52	.8667	96.3	1055.1	105.9	1106.9	116.0	1158.8	126.6	1211.0	52
53	.8833	96.5	1055.9	106.1	1107.8	116.1	1159.7	126.7	1211.8	53
54	.9000	96.7	1056.8	106.3	1108.6	116.3	1160.6	126.9	1212.7	54
55	.9167	96.8	1057.7	106.4	1109.4	116.5	1161.4	127.1	1213.6	55
56	.9333	97.0	1058.6	106.6	1110.3	116.7	1162.3	127.3	1214.5	56
57	.9500	97.1	1059.4	106.7	1111.2	116.8	1163.1	127.5	1215.3	57
58	.9667	97.3	1060.3	106.9	1112.1	117.0	1164.0	127.6	1216.2	58
59	.9833	97.4	1061.1	107.0	1112.9	117.2	1164.9	127.8	1217.1	59

Use 100′ Chords up to 8° Curves
Use 50′ Chords up to 16° Curves
Use 25′ Chords up to 32° Curves
Use 10′ Chords above 32° Curves

Minutes	Dec. of Degree	24°		25°		26°		27°		Minutes
		Ext.	Tan.	Ext.	Tan.	Ext.	Tan.	Ext.	Tan.	
0	.0000	128.0	1218.0	139.1	1270.3	150.7	1322.9	162.8	1375.6	0
1	.0167	128.2	1218.8	139.3	1271.1	150.9	1323.7	163.0	1376.5	1
2	.0333	128.4	1219.7	139.5	1272.0	151.1	1324.6	163.2	1377.4	2
3	.0500	128.5	1220.5	139.7	1272.9	151.3	1325.5	163.5	1378.3	3
4	.0667	128.7	1221.4	139.9	1273.8	151.5	1326.4	163.7	1379.2	4
5	.0833	128.9	1222.3	140.1	1274.6	151.7	1327.3	163.9	1380.0	5
6	.1000	129.1	1223.2	140.3	1275.5	151.9	1328.1	164.1	1380.9	6
7	.1167	129.3	1224.0	140.4	1276.4	152.1	1329.0	164.3	1381.8	7
8	.1333	129.5	1224.9	140.6	1277.3	152.3	1329.9	164.5	1382.7	8
9	.1500	129.7	1225.8	140.8	1278.2	152.5	1330.7	164.7	1383.6	9
10	.1667	129.8	1226.7	141.0	1279.1	152.7	1331.6	164.9	1384.5	10
11	.1833	130.0	1227.5	141.2	1279.9	152.9	1332.5	165.1	1385.3	11
12	.2000	130.2	1228.4	141.4	1280.8	153.1	1333.4	165.3	1386.2	12
13	.2167	130.4	1229.3	141.6	1281.6	153.3	1334.3	165.5	1387.1	13
14	.2333	130.6	1230.2	141.8	1282.5	153.5	1335.2	165.7	1388.0	14
15	.2500	130.7	1231.0	142.0	1283.4	153.7	1336.0	165.9	1388.9	15
16	.2667	130.9	1231.9	142.2	1284.3	153.9	1336.9	166.1	1389.8	16
17	.2833	131.1	1232.7	142.3	1285.2	154.1	1337.8	166.3	1390.6	17
18	.3000	131.3	1233.6	142.5	1286.1	154.3	1338.7	166.5	1391.5	18
19	.3167	131.5	1234.5	142.7	1286.9	154.5	1339.5	166.7	1392.4	19
20	.3333	131.7	1235.4	142.9	1287.8	154.7	1340.4	167.0	1393.3	20
21	.3500	131.9	1236.2	143.1	1288.7	154.9	1341.3	167.2	1394.1	21
22	.3667	132.0	1237.1	143.3	1289.6	155.1	1342.2	167.4	1395.0	22
23	.3833	132.2	1238.0	143.5	1290.4	155.3	1343.0	167.6	1395.9	23
24	.4000	132.4	1238.9	143.7	1291.3	155.5	1343.9	167.8	1396.8	24
25	.4167	132.6	1239.7	143.9	1292.2	155.7	1344.8	168.0	1397.7	25
26	.4333	132.8	1240.6	144.1	1293.1	155.9	1345.7	168.2	1398.6	26
27	.4500	133.0	1241.5	144.3	1293.9	156.1	1346.5	168.4	1399.4	27
28	.4667	133.1	1242.4	144.5	1294.8	156.3	1347.4	168.6	1400.3	28
29	.4833	133.3	1243.2	144.7	1295.7	156.5	1348.3	168.9	1401.2	29
30	.5000	133.5	1244.1	144.9	1296.6	156.7	1349.2	169.1	1402.1	30
31	.5167	133.7	1244.9	145.1	1297.4	156.9	1350.1	169.3	1403.0	31
32	.5333	133.9	1245.8	145.3	1298.3	157.1	1351.0	169.5	1403.9	32
33	.5500	134.0	1246.7	145.5	1299.2	157.3	1351.8	169.7	1404.7	33
34	.5667	134.2	1247.6	145.6	1300.1	157.5	1352.7	169.9	1405.6	34
35	.5833	134.4	1248.4	145.8	1300.9	157.7	1353.6	170.1	1406.5	35
36	.6000	134.6	1249.3	146.0	1301.8	157.9	1354.5	170.3	1407.4	36
37	.6167	134.9	1250.2	146.2	1302.7	158.1	1355.3	170.5	1408.3	37
38	.6333	135.0	1251.1	146.4	1303.6	158.3	1356.2	170.8	1409.2	38
39	.6500	135.2	1251.9	146.6	1304.4	158.5	1357.1	171.0	1410.0	39
40	.6667	135.4	1252.8	146.8	1305.3	158.7	1358.0	171.2	1410.9	40
41	.6833	135.6	1253.7	147.0	1306.2	158.9	1358.9	171.4	1411.8	41
42	.7000	135.7	1254.6	147.2	1307.1	159.1	1359.8	171.6	1412.7	42
43	.7167	135.9	1255.4	147.4	1307.9	159.3	1360.6	171.8	1413.6	43
44	.7333	136.1	1256.3	147.6	1308.8	159.5	1361.5	172.0	1414.5	44
45	.7500	136.3	1257.2	147.8	1309.7	159.7	1362.4	172.2	1415.4	45
46	.7667	136.5	1258.1	148.0	1310.6	160.0	1363.3	172.5	1416.3	46
47	.7833	136.7	1258.9	148.2	1311.5	160.2	1364.2	172.7	1417.1	47
48	.8000	136.9	1259.8	148.4	1312.4	160.4	1365.1	172.9	1418.0	48
49	.8167	137.1	1260.7	148.6	1313.2	160.6	1365.9	173.1	1418.9	49
50	.8333	137.2	1261.5	148.8	1314.1	160.8	1366.8	173.3	1419.8	50
51	.8500	137.4	1262.4	149.0	1315.0	161.0	1367.7	173.5	1420.7	51
52	.8667	137.6	1263.3	149.2	1315.9	161.2	1368.6	173.7	1421.6	52
53	.8833	137.8	1264.1	149.4	1316.7	161.4	1369.5	173.9	1422.4	53
54	.9000	138.0	1265.0	149.5	1317.6	161.6	1370.4	174.1	1423.3	54
55	.9167	138.2	1265.9	149.7	1318.5	161.8	1371.2	174.4	1424.2	55
56	.9333	138.4	1266.8	149.9	1319.4	162.0	1372.1	174.6	1425.1	56
57	.9500	138.6	1267.6	150.1	1320.3	162.2	1373.0	174.8	1426.0	57
58	.9667	138.7	1268.5	150.3	1321.1	162.4	1373.9	175.0	1426.9	58
59	.9833	138.9	1269.4	150.5	1322.0	162.6	1374.7	175.2	1427.7	59

Use 100′ Chords up to 8° Curves
Use 50′ Chords up to 16° Curves
Use 25′ Chords up to 32° Curves
Use 10′ Chords above 32° Curves

Minutes	Dec. of Degree	28°		29°		30°		31°		Minutes
		Ext.	Tan.	Ext.	Tan.	Ext.	Tan.	Ext.	Tan.	
0	.0000	175.4	1428.6	188.5	1481.9	202.1	1535.3	216.3	1589.0	0
1	.0167	175.6	1429.5	188.7	1482.8	202.3	1536.2	216.5	1589.9	1
2	.0333	175.8	1430.4	189.0	1483.7	202.6	1537.1	216.8	1590.8	2
3	.0500	176.0	1431.3	189.2	1484.5	202.8	1538.0	217.0	1591.7	3
4	.0667	176.3	1432.2	189.4	1485.4	203.1	1538.9	217.2	1592.6	4
5	.0833	176.5	1433.1	189.6	1486.3	203.3	1539.8	217.4	1593.5	5
6	.1000	176.7	1434.0	189.9	1487.2	203.5	1540.7	217.7	1594.4	6
7	.1167	176.9	1434.8	190.1	1488.1	203.7	1541.6	217.9	1595.3	7
8	.1333	177.1	1435.7	190.3	1489.0	204.0	1542.5	218.2	1596.2	8
9	.1500	177.3	1436.6	190.5	1489.9	204.2	1543.4	218.4	1597.1	9
10	.1667	177.6	1437.5	190.8	1490.8	204.5	1544.3	218.7	1598.0	10
11	.1833	177.8	1438.4	191.0	1491.7	204.7	1545.2	218.9	1598.9	11
12	.2000	178.0	1439.3	191.2	1492.6	204.9	1546.0	219.2	1599.8	12
13	.2167	178.2	1440.2	191.5	1493.4	205.1	1546.9	219.4	1600.7	13
14	.2333	178.4	1441.1	191.7	1494.3	205.4	1547.8	219.6	1601.6	14
15	.2500	178.6	1441.9	191.9	1495.2	205.6	1548.7	219.8	1602.5	15
16	.2667	178.9	1442.8	192.1	1496.1	205.9	1549.6	220.1	1603.4	16
17	.2833	179.1	1443.7	192.3	1497.0	206.1	1550.5	220.3	1604.3	17
18	.3000	179.3	1444.6	192.5	1497.9	206.3	1551.4	220.6	1605.2	18
19	.3167	179.5	1445.5	192.7	1498.8	206.5	1552.3	220.8	1606.1	19
20	.3333	179.7	1446.4	193.0	1499.7	206.8	1553.2	221.1	1607.0	20
21	.3500	179.9	1447.3	193.2	1500.6	207.0	1554.1	221.3	1607.9	21
22	.3667	180.2	1448.2	193.5	1501.5	207.3	1555.0	221.6	1608.8	22
23	.3833	180.4	1449.0	193.7	1502.3	207.5	1555.9	221.8	1609.7	23
24	.4000	180.6	1449.9	193.9	1503.2	207.7	1556.8	222.1	1610.6	24
25	.4167	180.8	1450.8	194.1	1504.1	207.9	1557.7	222.3	1611.5	25
26	.4333	181.0	1451.7	194.4	1505.0	208.2	1558.6	222.6	1612.4	26
27	.4500	181.2	1452.6	194.6	1505.9	208.4	1559.5	222.8	1613.3	27
28	.4667	181.5	1453.5	194.8	1506.8	208.7	1560.4	223.0	1614.2	28
29	.4833	181.7	1454.3	195.0	1507.7	208.9	1561.3	223.2	1615.1	29
30	.5000	181.9	1455.2	195.3	1508.6	209.1	1562.2	223.5	1616.0	30
31	.5167	182.1	1456.1	195.5	1509.5	209.3	1563.1	223.7	1616.9	31
32	.5333	182.3	1457.0	195.7	1510.4	209.6	1564.0	224.0	1617.8	32
33	.5500	182.5	1457.9	195.9	1511.2	209.8	1564.9	224.2	1618.7	33
34	.5667	182.8	1458.8	196.2	1512.1	210.1	1565.7	224.5	1619.6	34
35	.5833	183.0	1459.7	196.4	1513.0	210.3	1566.6	224.7	1620.5	35
36	.6000	183.2	1460.6	196.7	1513.9	210.5	1567.5	225.0	1621.4	36
37	.6167	183.4	1461.4	196.9	1514.8	210.7	1568.4	225.2	1622.3	37
38	.6333	183.6	1462.3	197.1	1515.7	211.0	1569.3	225.5	1623.2	38
39	.6500	183.8	1463.2	197.3	1516.6	211.2	1570.2	225.7	1624.1	39
40	.6667	184.1	1464.1	197.6	1517.5	211.5	1571.1	226.0	1625.0	40
41	.6833	184.3	1465.0	197.8	1518.4	211.7	1572.0	226.2	1625.9	41
42	.7000	184.5	1465.9	198.0	1519.3	212.0	1572.9	226.5	1626.8	42
43	.7167	184.7	1466.8	198.2	1520.1	212.2	1573.8	226.7	1627.7	43
44	.7333	185.0	1467.7	198.5	1521.0	212.4	1574.7	227.0	1628.6	44
45	.7500	185.2	1468.6	198.7	1521.9	212.6	1575.6	227.2	1629.5	45
46	.7667	185.4	1469.5	198.9	1522.8	212.9	1576.5	227.5	1630.5	46
47	.7833	185.6	1470.3	199.1	1523.7	213.1	1577.4	227.7	1631.4	47
48	.8000	185.9	1471.2	199.4	1524.6	213.4	1578.3	228.0	1632.3	48
49	.8167	186.1	1472.1	199.6	1525.5	213.6	1579.2	228.2	1633.2	49
50	.8333	186.3	1473.0	199.8	1526.4	213.9	1580.1	228.4	1634.1	50
51	.8500	186.5	1473.9	200.0	1527.3	214.1	1581.0	228.6	1635.0	51
52	.8667	186.8	1474.8	200.3	1528.2	214.4	1581.9	228.9	1635.9	52
53	.8833	187.0	1475.7	200.5	1529.1	214.6	1582.8	229.1	1636.8	53
54	.9000	187.2	1476.6	200.8	1530.0	214.8	1583.7	229.4	1637.7	54
55	.9167	187.4	1477.4	201.0	1530.9	215.0	1584.6	229.6	1638.6	55
56	.9333	187.6	1478.3	201.2	1531.7	215.3	1585.5	229.9	1639.5	56
57	.9500	187.8	1479.2	201.4	1532.6	215.5	1586.3	230.1	1640.4	57
58	.9667	188.1	1480.1	201.7	1533.5	215.8	1587.2	230.4	1641.3	58
59	.9833	188.3	1481.0	201.9	1534.4	216.0	1588.1	230.6	1642.2	59

Use 100′ Chords up to 8° Curves Use 25′ Chords up to 32° Curves
Use 50′ Chords up to 16° Curves Use 10′ Chords above 32° Curves

Minutes	Dec. of Degree	32° Ext.	32° Tan.	33° Ext.	33° Tan.	34° Ext.	34° Tan.	35° Ext.	35° Tan.	Minutes
0	.0000	230.9	1643.1	246.1	1697.3	261.8	1751.8	278.1	1806.7	0
1	.0167	231.1	1644.0	246.3	1698.2	262.0	1752.7	278.4	1807.6	1
2	.0333	231.4	1644.9	246.6	1699.1	262.3	1753.7	278.6	1808.5	2
3	.0500	231.6	1645.8	246.8	1700.0	262.6	1754.6	278.9	1809.4	3
4	.0667	231.9	1646.7	247.1	1700.9	262.9	1755.5	279.2	1810.3	4
5	.0833	232.1	1647.6	247.4	1701.8	263.1	1756.4	279.4	1811.2	5
6	.1000	232.4	1648.5	247.7	1702.7	263.4	1757.3	279.7	1812.2	6
7	.1167	232.6	1649.4	247.9	1703.6	263.7	1758.2	280.0	1813.1	7
8	.1333	232.9	1650.3	248.2	1704.5	264.0	1759.1	280.3	1814.0	8
9	.1500	233.1	1651.2	248.4	1705.4	264.2	1760.0	280.6	1814.9	9
10	.1667	233.4	1652.1	248.7	1706.4	264.5	1761.0	280.8	1815.8	10
11	.1833	233.6	1653.0	248.9	1707.3	264.7	1761.9	281.1	1816.7	11
12	.2000	233.9	1653.9	249.2	1708.2	265.0	1762.8	281.4	1817.7	12
13	.2167	234.1	1654.8	249.4	1709.1	265.3	1763.7	281.6	1818.6	13
14	.2333	234.4	1655.7	249.7	1710.0	265.6	1764.6	281.9	1819.5	14
15	.2500	234.6	1656.6	249.9	1710.9	265.9	1765.5	282.2	1820.4	15
16	.2667	234.9	1657.5	250.2	1711.8	266.1	1766.4	282.5	1821.3	16
17	.2833	235.1	1658.4	250.5	1712.7	266.4	1767.3	282.7	1822.2	17
18	.3000	235.4	1659.3	250.8	1713.6	266.7	1768.3	283.0	1823.2	18
19	.3167	235.6	1660.2	251.0	1714.5	266.9	1769.2	283.3	1824.1	19
20	.3333	235.9	1661.1	251.3	1715.5	267.2	1770.1	283.6	1825.0	20
21	.3500	236.1	1662.0	251.5	1716.4	267.4	1771.0	283.9	1825.9	21
22	.3667	236.4	1662.9	251.8	1717.3	267.7	1771.9	284.2	1826.8	22
23	.3833	236.6	1663.8	252.0	1718.2	268.0	1772.8	284.4	1827.7	23
24	.4000	236.9	1664.7	252.3	1719.1	268.3	1773.7	284.7	1828.7	24
25	.4167	237.1	1665.6	252.6	1720.0	268.6	1774.6	285.0	1829.6	25
26	.4333	237.4	1666.5	252.9	1720.9	263.8	1775.6	285.3	1830.5	26
27	.4500	237.6	1667.4	253.1	1721.8	269.1	1776.5	285.6	1831.4	27
28	.4667	237.9	1668.3	253.4	1722.7	269.3	1777.4	285.9	1832.3	28
29	.4833	238.1	1669.2	253.6	1723.6	269.6	1778.3	286.1	1833.2	29
30	.5000	238.4	1670.1	253.9	1724.6	269.9	1779.2	286.4	1834.2	30
31	.5167	238.7	1671.0	254.1	1725.5	270.1	1780.1	286.7	1835.1	31
32	.5333	239.0	1671.9	254.4	1726.4	270.4	1781.0	287.0	1836.0	32
33	.5500	239.2	1672.8	254.7	1727.3	270.7	1781.9	287.2	1836.9	33
34	.5667	239.5	1673.7	255.0	1728.2	271.0	1782.9	287.5	1837.8	34
35	.5833	239.7	1674.6	255.2	1729.1	271.2	1783.8	287.8	1838.7	35
36	.6000	240.0	1675.5	255.5	1730.0	271.5	1784.7	288.1	1839.7	36
37	.6167	240.2	1676.4	255.7	1730.9	271.7	1785.6	288.4	1840.6	37
38	.6333	240.5	1677.4	256.0	1731.8	272.0	1786.5	288.7	1841.5	38
39	.6500	240.7	1678.3	256.2	1732.7	272.3	1787.4	289.0	1842.4	39
40	.6667	241.0	1679.2	256.5	1733.6	272.6	1788.4	289.2	1843.4	40
41	.6833	241.2	1680.1	256.8	1734.5	272.9	1789.3	289.5	1844.3	41
42	.7000	241.5	1681.0	257.1	1735.5	273.1	1790.2	289.8	1845.2	42
43	.7167	241.7	1681.9	257.3	1736.4	273.4	1791.1	290.1	1846.1	43
44	.7333	242.0	1682.8	257.6	1737.3	273.7	1792.0	290.4	1847.1	44
45	.7500	242.2	1683.7	257.8	1738.2	274.0	1792.9	290.6	1848.0	45
46	.7667	242.5	1684.6	258.1	1739.1	274.2	1793.9	290.9	1848.9	46
47	.7833	242.7	1685.5	258.3	1740.0	274.5	1794.8	291.2	1849.8	47
48	.8000	243.0	1686.4	258.6	1740.9	274.8	1795.7	291.5	1850.7	48
49	.8167	243.2	1687.3	258.9	1741.8	275.0	1796.6	291.8	1851.6	49
50	.8333	243.5	1688.2	259.2	1742.7	275.3	1797.5	292.0	1852.6	50
51	.8500	243.8	1689.1	259.4	1743.6	275.6	1798.4	292.3	1853.5	51
52	.8667	244.1	1690.0	259.7	1744.6	275.9	1799.3	292.6	1854.4	52
53	.8833	244.3	1690.9	259.9	1745.5	276.1	1800.2	292.9	1855.3	53
54	.9000	244.6	1691.8	260.2	1746.4	276.4	1801.2	293.2	1856.3	54
55	.9167	244.8	1692.7	260.5	1747.3	276.7	1802.1	293.4	1857.2	55
56	.9333	245.1	1693.7	260.8	1748.2	277.0	1803.0	293.7	1858.1	56
57	.9500	245.3	1694.6	261.0	1749.1	277.3	1803.9	294.0	1859.0	57
58	.9667	245.6	1695.5	261.3	1750.0	277.5	1804.8	294.3	1859.9	58
59	.9833	245.8	1696.4	261.5	1750.9	277.8	1805.7	294.6	1860.8	59

Use 100′ Chords up to 8° Curves
Use 50′ Chords up to 16° Curves
Use 25′ Chords up to 32° Curves
Use 10′ Chords above 32° Curves

Minutes	Dec. of Degree	36°		37°		38°		39°		Minutes
		Ext.	Tan.	Ext.	Tan.	Ext.	Tan.	Ext.	Tan.	
0	.0000	294.9	1861.8	312.3	1917.3	330.2	1973.0	348.7	2029.1	0
1	.0167	295.2	1862.7	312.5	1918.2	330.5	1973.9	349.0	2030.0	1
2	.0333	295.4	1863.6	312.8	1919.1	330.8	1974.9	349.3	2031.0	2
3	.0500	295.7	1864.5	313.1	1920.0	331.1	1975.8	349.6	2031.9	3
4	.0667	296.0	1865.5	313.4	1921.0	331.4	1976.7	349.9	2032.9	4
5	.0833	296.3	1866.4	313.7	1921.9	331.7	1977.6	350.3	2033.8	5
6	.1000	296.6	1867.3	314.0	1922.8	332.0	1978.6	350.6	2034.7	6
7	.1167	296.9	1868.2	314.3	1923.7	332.3	1979.5	350.9	2035.6	7
8	.1333	297.2	1869.2	314.6	1924.7	332.6	1980.5	351.2	2036.6	8
9	.1500	297.5	1870.1	314.9	1925.6	332.9	1981.4	351.5	2037.5	9
10	.1667	297.7	1871.0	315.2	1926.5	333.2	1982.3	351.8	2038.5	10
11	.1833	298.0	1871.9	315.5	1927.4	333.5	1983.2	352.1	2039.4	11
12	.2000	298.3	1872.9	315.8	1928.4	333.8	1984.2	352.4	2040.4	12
13	.2167	298.6	1873.8	316.1	1929.3	334.2	1985.1	352.8	2041.3	13
14	.2333	298.9	1874.7	316.4	1930.2	334.5	1986.1	353.1	2042.3	14
15	.2500	299.2	1875.6	316.7	1931.1	334.8	1987.0	353.4	2043.2	15
16	.2667	299.5	1876.5	317.0	1932.1	335.1	1987.9	353.7	2044.1	16
17	.2833	299.7	1877.4	317.2	1933.0	335.4	1988.8	354.0	2045.0	17
18	.3000	300.0	1878.4	317.5	1933.9	335.7	1989.8	354.3	2046.0	18
19	.3167	300.3	1879.3	317.8	1934.8	336.0	1990.7	354.6	2046.9	19
20	.3333	300.6	1880.2	318.1	1935.8	336.3	1991.7	354.9	2047.9	20
21	.3500	300.9	1881.1	318.4	1936.7	336.6	1992.6	355.3	2048.8	21
22	.3667	301.2	1882.1	318.7	1937.6	336.9	1993.6	355.6	2049.8	22
23	.3833	301.5	1883.0	319.0	1938.5	337.2	1994.5	355.9	2050.7	23
24	.4000	301.8	1883.9	319.3	1939.5	337.5	1995.4	356.2	2051.7	24
25	.4167	302.0	1884.8	319.6	1940.4	337.8	1996.3	356.6	2052.6	25
26	.4333	302.3	1885.8	319.9	1941.3	338.1	1997.3	356.9	2053.5	26
27	.4500	302.6	1886.7	320.2	1942.2	338.4	1998.2	357.2	2054.4	27
28	.4667	302.9	1887.6	320.5	1943.2	338.7	1999.2	357.5	2055.4	28
29	.4833	303.2	1888.5	320.8	1944.1	339.1	2000.1	357.8	2056.3	29
30	.5000	303.5	1889.5	321.1	1945.0	339.4	2001.0	358.1	2057.3	30
31	.5167	303.8	1890.4	321.4	1945.9	339.7	2001.9	358.4	2058.2	31
32	.5333	304.1	1891.3	321.7	1946.9	340.0	2002.9	358.8	2059.2	32
33	.5500	304.3	1892.2	322.0	1947.8	340.3	2003.8	359.1	2060.1	33
34	.5667	304.6	1893.2	322.3	1948.8	340.6	2004.8	359.4	2061.1	34
35	.5833	304.9	1894.1	322.6	1949.7	340.9	2005.7	359.8	2062.0	35
36	.6000	305.2	1895.0	322.9	1950.6	341.2	2006.6	360.1	2063.0	36
37	.6167	305.5	1895.9	323.2	1951.5	341.5	2007.5	360.4	2063.9	37
38	.6333	305.8	1896.9	323.5	1952.5	341.8	2008.5	360.7	2064.8	38
39	.6500	306.1	1897.8	323.8	1953.4	342.1	2009.4	361.0	2065.7	39
40	.6667	306.4	1898.7	324.2	1954.4	342.4	2010.4	361.3	2066.7	40
41	.6833	306.7	1899.6	324.5	1955.3	342.8	2011.3	361.6	2067.6	41
42	.7000	307.0	1900.6	324.8	1956.2	343.1	2012.3	362.0	2068.6	42
43	.7167	307.2	1901.5	325.1	1957.1	343.4	2013.2	362.3	2069.5	43
44	.7333	307.5	1902.4	325.4	1958.1	343.7	2014.1	362.6	2070.5	44
45	.7500	307.8	1903.3	325.7	1959.0	344.0	2015.0	363.0	2071.4	45
46	.7667	308.1	1904.3	326.0	1960.0	344.3	2016.0	363.3	2072.4	46
47	.7833	308.4	1905.2	326.3	1960.9	344.6	2016.9	363.6	2073.3	47
48	.8000	308.7	1906.1	326.6	1961.8	344.9	2017.9	363.9	2074.2	48
49	.8167	309.0	1907.0	326.9	1962.7	345.3	2018.8	364.2	2075.1	49
50	.8333	309.3	1908.0	327.2	1963.7	345.6	2019.7	364.5	2076.1	50
51	.8500	309.6	1908.9	327.5	1964.6	345.9	2020.6	364.9	2077.0	51
52	.8667	309.9	1909.8	327.8	1965.5	346.2	2021.6	365.2	2078.0	52
53	.8833	310.2	1910.7	328.1	1966.4	346.5	2022.5	365.5	2078.9	53
54	.9000	310.5	1911.7	328.4	1967.4	346.8	2023.5	365.8	2079.9	54
55	.9167	310.8	1912.6	328.7	1968.3	347.1	2024.4	366.2	2080.8	55
56	.9333	311.1	1913.5	329.0	1969.3	347.4	2025.4	366.5	2081.8	56
57	.9500	311.4	1914.4	329.3	1970.2	347.8	2026.3	366.8	2082.7	57
58	.9667	311.7	1915.4	329.6	1971.1	348.1	2027.2	367.1	2083.7	58
59	.9833	312.0	1916.3	329.9	1972.0	348.4	2028.1	367.4	2084.6	59

Use 100′ Chords up to 8° Curves
Use 50′ Chords up to 16° Curves
Use 25′ Chords up to 32° Curves
Use 10′ Chords above 32° Curves

Minutes	Dec. of Degree	40° Ext.	40° Tan.	41° Ext.	41° Tan.	42° Ext.	42° Tan.	43° Ext.	43° Tan.	Minutes
0	.0000	367.7	2085.5	387.4	2142.3	407.7	2199.5	428.6	2257.1	0
1	.0167	368.0	2086.4	387.8	2143.2	408.0	2200.4	429.0	2258.0	1
2	.0333	368.4	2087.4	388.1	2144.2	408.3	2201.4	429.3	2259.0	2
3	.0500	368.7	2088.3	388.5	2145.1	408.7	2202.3	429.7	2260.0	3
4	.0667	369.0	2089.3	388.8	2146.1	409.0	2203.3	430.0	2261.0	4
5	.0833	369.4	2090.2	389.1	2147.0	409.4	2204.3	430.4	2261.9	5
6	.1000	369.7	2091.2	389.4	2148.0	409.7	2205.3	430.7	2262.9	6
7	.1167	370.0	2092.1	389.8	2148.9	410.1	2206.2	431.1	2263.8	7
8	.1333	370.3	2093.1	390.1	2149.9	410.4	2207.2	431.4	2264.8	8
9	.1500	370.7	2094.0	390.4	2150.9	410.8	2208.1	431.8	2265.7	9
10	.1667	371.0	2095.0	390.7	2151.9	411.1	2209.1	432.1	2266.7	10
11	.1833	371.3	2095.9	391.1	2152.8	411.5	2210.0	432.4	2267.7	11
12	.2000	371.6	2096.9	391.4	2153.8	411.8	2211.0	432.8	2268.7	12
13	.2167	372.0	2097.8	391.8	2154.7	412.2	2211.9	433.2	2269.6	13
14	.2333	372.3	2098.8	392.1	2155.7	412.5	2212.9	433.5	2270.6	14
15	.2500	372.6	2099.7	392.4	2156.6	412.9	2213.9	433.9	2271.5	15
16	.2667	372.9	2100.7	392.7	2157.6	413.2	2214.9	434.2	2272.5	16
17	.2833	373.3	2101.6	393.1	2158.5	413.6	2215.8	434.6	2273.5	17
18	.3000	373.6	2102.6	393.4	2159.5	413.9	2216.8	434.9	2274.5	18
19	.3167	374.0	2103.5	393.7	2160.4	414.3	2217.7	435.3	2275.4	19
20	.3333	374.3	2104.5	394.1	2161.4	414.6	2218.7	435.6	2276.4	20
21	.3500	374.6	2105.4	394.4	2162.3	415.0	2219.6	436.0	2277.3	21
22	.3667	374.9	2106.3	394.7	2163.3	415.3	2220.6	436.3	2278.3	22
23	.3833	375.3	2107.2	395.1	2164.2	415.7	2221.5	436.7	2279.2	23
24	.4000	375.6	2108.2	395.4	2165.2	416.0	2222.5	437.0	2280.2	24
25	.4167	375.9	2109.1	395.8	2166.1	416.3	2223.4	437.4	2281.2	25
26	.4333	376.2	2110.1	396.1	2167.1	416.6	2224.4	437.8	2282.2	26
27	.4500	376.6	2111.0	396.5	2168.0	417.0	2225.4	438.2	2283.1	27
28	.4667	376.9	2112.0	396.8	2169.0	417.3	2226.4	438.5	2284.1	28
29	.4833	377.2	2112.9	397.2	2169.9	417.7	2227.3	438.9	2285.0	29
30	.5000	377.5	2113.9	397.5	2170.9	418.0	2228.3	439.2	2286.0	30
31	.5167	377.9	2114.8	397.8	2171.8	418.4	2229.2	439.6	2287.0	31
32	.5333	378.2	2115.8	398.1	2172.8	418.7	2230.2	439.9	2288.0	32
33	.5500	378.5	2116.7	398.5	2173.7	419.1	2231.1	440.3	2288.9	33
34	.5667	378.8	2117.7	398.8	2174.7	419.4	2232.1	440.6	2289.9	34
35	.5833	379.2	2118.6	399.2	2175.6	419.8	2233.0	441.0	2290.8	35
36	.6000	379.5	2119.6	399.5	2176.6	420.1	2234.0	441.4	2291.8	36
37	.6167	379.8	2120.5	399.9	2177.5	420.5	2235.0	441.8	2292.8	37
38	.6333	380.1	2121.5	400.2	2178.5	420.8	2236.0	442.1	2293.8	38
39	.6500	380.5	2122.4	400.6	2179.4	421.2	2236.9	442.5	2294.7	39
40	.6667	380.8	2123.4	400.9	2180.4	421.5	2237.9	442.8	2295.7	40
41	.6833	381.1	2124.3	401.2	2181.4	421.9	2238.8	443.2	2296.7	41
42	.7000	381.4	2125.3	401.5	2182.4	422.2	2239.8	443.5	2297.7	42
43	.7167	381.8	2126.2	401.9	2183.3	422.6	2240.7	443.9	2298.6	43
44	.7333	382.1	2127.2	402.2	2184.3	422.9	2241.7	444.2	2299.6	44
45	.7500	382.5	2128.1	402.6	2185.2	423.3	2242.6	444.6	2300.5	45
46	.7667	382.8	2129.1	402.9	2186.2	423.6	2243.6	445.0	2301.5	46
47	.7833	383.1	2130.0	403.3	2187.1	424.0	2244.6	445.4	2302.5	47
48	.8000	383.4	2131.0	403.6	2188.1	424.3	2245.6	445.7	2303.5	48
49	.8167	383.8	2131.9	404.0	2189.0	424.7	2246.5	446.1	2304.4	49
50	.8333	384.1	2132.9	404.3	2190.0	425.0	2247.5	446.4	2305.4	50
51	.8500	384.5	2133.8	404.6	2190.9	425.4	2248.4	446.8	2306.3	51
52	.8667	384.8	2134.7	404.9	2191.9	425.7	2249.4	447.1	2307.3	52
53	.8833	385.1	2135.6	405.3	2192.8	426.1	2250.3	447.5	2308.3	53
54	.9000	385.4	2136.6	405.6	2193.8	426.4	2251.3	447.8	2309.3	54
55	.9167	385.8	2137.5	406.0	2194.7	426.8	2252.3	448.2	2310.2	55
56	.9333	386.1	2138.5	406.3	2195.7	427.1	2253.3	448.6	2311.2	56
57	.9500	386.5	2139.4	406.7	2196.6	427.5	2254.2	449.0	2312.1	57
58	.9667	386.8	2140.4	407.0	2197.6	427.8	2255.2	449.3	2313.1	58
59	.9833	387.1	2141.3	407.4	2198.5	428.2	2256.1	449.7	2314.1	59

Use 100′ Chords up to 8° Curves
Use 50′ Chords up to 16° Curves
Use 25′ Chords up to 32° Curves
Use 10′ Chords above 32° Curves

Minutes	Dec. of Degree	44°		45°		46°		47°		Minutes
		Ext.	Tan.	Ext.	Tan.	Ext.	Tan.	Ext.	Tan.	
0	.0000	450.0	2315.1	472.1	2373.4	494.8	2432.2	518.3	2491.5	0
1	.0167	450.4	2316.0	472.5	2374.4	495.2	2433.2	518.7	2492.4	1
2	.0333	450.7	2317.0	472.9	2375.4	495.6	2434.2	519.0	2493.4	2
3	.0500	451.1	2318.0	473.3	2376.3	496.0	2435.1	519.4	2494.4	3
4	.0667	451.5	2319.0	473.6	2377.3	496.4	2436.1	519.8	2495.4	4
5	.0833	451.9	2319.9	474.0	2378.3	496.7	2437.1	520.2	2496.4	5
6	.1000	452.2	2320.9	474.4	2379.3	497.2	2438.1	520.6	2497.4	6
7	.1167	452.6	2321.8	474.8	2380.2	497.6	2439.1	521.0	2498.4	7
8	.1333	452.9	2322.8	475.1	2381.2	497.9	2440.1	521.4	2499.4	8
9	.1500	453.3	2323.8	475.5	2382.2	498.3	2441.1	521.8	2500.4	9
10	.1667	453.7	2324.8	475.9	2383.2	498.7	2442.1	522.2	2501.4	10
11	.1833	454.1	2325.7	476.3	2384.2	499.1	2443.0	522.6	2502.4	11
12	.2000	454.4	2326.7	476.6	2385.2	499.5	2444.0	523.0	2503.4	12
13	.2167	454.8	2327.7	477.0	2386.1	499.9	2445.0	523.4	2504.4	13
14	.2333	455.1	2328.7	477.4	2387.1	500.3	2446.0	523.8	2505.4	14
15	.2500	455.5	2329.6	477.8	2388.1	500.7	2447.0	524.2	2506.3	15
16	.2667	455.9	2330.6	478.1	2389.1	501.0	2448.0	524.6	2507.3	16
17	.2833	456.3	2331.6	478.5	2390.0	501.4	2449.0	525.0	2508.3	17
18	.3000	456.6	2332.6	478.9	2391.0	501.8	2449.9	525.4	2509.3	18
19	.3167	457.0	2333.5	479.3	2392.0	502.2	2450.9	525.8	2510.3	19
20	.3333	457.3	2334.5	479.6	2393.0	502.6	2451.9	526.2	2511.3	20
21	.3500	457.7	2335.4	480.0	2393.9	503.0	2452.9	526.6	2512.3	21
22	.3667	458.1	2336.4	480.4	2394.9	503.4	2453.9	527.0	2513.3	22
23	.3833	458.5	2337.4	480.8	2395.9	503.8	2454.9	527.4	2514.3	23
24	.4000	458.8	2338.4	481.1	2396.9	504.1	2455.9	527.8	2515.3	24
25	.4167	459.2	2339.3	481.5	2397.8	504.5	2456.8	528.2	2516.3	25
26	.4333	459.5	2340.3	481.9	2398.8	504.9	2457.8	528.6	2517.3	26
27	.4500	459.9	2341.3	482.3	2399.8	505.3	2458.8	529.0	2518.3	27
28	.4667	460.3	2342.3	482.6	2400.8	505.7	2459.8	529.4	2519.3	28
29	.4833	460.7	2343.2	483.0	2401.8	506.1	2460.8	529.8	2520.2	29
30	.5000	461.0	2344.2	483.4	2402.8	506.5	2461.8	530.2	2521.2	30
31	.5167	461.4	2345.1	483.8	2403.7	506.9	2462.8	530.6	2522.2	31
32	.5333	461.7	2346.1	484.2	2404.7	507.3	2463.8	531.0	2523.2	32
33	.5500	462.1	2347.1	484.6	2405.7	507.7	2464.7	531.4	2524.2	33
34	.5667	462.5	2348.1	484.9	2406.7	508.0	2465.7	531.8	2525.2	34
35	.5833	462.9	2349.0	485.3	2407.6	508.4	2466.7	532.2	2526.2	35
36	.6000	463.2	2350.0	485.7	2408.6	508.8	2467.7	532.6	2527.2	36
37	.6167	463.6	2351.0	486.1	2409.6	509.2	2468.7	533.0	2528.2	37
38	.6333	463.9	2352.0	486.5	2410.6	509.6	2469.7	533.4	2529.2	38
39	.6500	464.3	2352.9	486.9	2411.6	510.0	2470.7	533.8	2530.2	39
40	.6667	464.7	2353.9	487.2	2412.6	510.4	2471.7	534.2	2531.2	40
41	.6833	465.0	2354.9	487.6	2413.5	510.8	2472.6	534.6	2532.2	41
42	.7000	465.4	2355.9	488.0	2414.5	511.1	2473.6	535.0	2533.2	42
43	.7167	465.8	2356.8	488.4	2415.5	511.5	2474.6	535.4	2534.2	43
44	.7333	466.2	2357.8	488.7	2416.5	511.9	2475.6	535.8	2535.2	44
45	.7500	466.5	2358.8	489.1	2417.5	512.3	2476.6	536.2	2536.2	45
46	.7667	466.9	2359.8	489.5	2418.5	512.7	2477.6	536.6	2537.2	46
47	.7833	467.3	2360.7	489.9	2419.4	513.1	2478.6	537.0	2538.2	47
48	.8000	467.7	2361.7	490.3	2420.4	513.5	2479.6	537.4	2539.2	48
49	.8167	468.0	2362.7	490.7	2421.4	513.9	2480.6	537.8	2540.2	49
50	.8333	468.4	2363.7	491.0	2422.4	514.3	2481.6	538.2	2541.2	50
51	.8500	468.8	2364.6	491.4	2423.4	514.7	2482.5	538.6	2542.2	51
52	.8667	469.1	2365.6	491.8	2424.4	515.1	2483.5	539.0	2543.2	52
53	.8833	469.5	2366.6	492.2	2425.3	515.5	2484.5	539.4	2544.2	53
54	.9000	469.9	2367.6	492.5	2426.3	515.9	2485.5	539.8	2545.2	54
55	.9167	470.3	2368.5	492.9	2427.3	516.3	2486.5	540.2	2546.2	55
56	.9333	470.6	2369.5	493.3	2428.3	516.7	2487.5	540.6	2547.2	56
57	.9500	471.0	2370.5	493.7	2429.2	517.1	2488.5	541.0	2548.2	57
58	.9667	471.4	2371.5	494.1	2430.2	517.5	2489.5	541.4	2549.2	58
59	.9833	471.8	2372.4	494.5	2431.2	517.9	2490.5	541.9	2550.1	59

Use 100′ Chords up to 8° Curves Use 25′ Chords up to 32° Curves
Use 50′ Chords up to 16° Curves Use 10′ Chords above 32° Curves

Minutes	Dec. of Degree	48° Ext.	48° Tan.	49° Ext.	49° Tan.	50° Ext.	50° Tan.	51° Ext.	51° Tan.	Minutes
0	.0000	542.3	2551.1	567.0	2611.3	592.4	2671.9	618.5	2733.0	0
1	.0167	542.7	2552.1	567.4	2612.3	592.8	2672.9	618.9	2734.1	1
2	.0333	543.1	2553.1	567.8	2613.3	593.2	2673.9	619.3	2735.1	2
3	.0500	543.5	2554.1	568.3	2614.3	593.7	2675.0	619.8	2736.1	3
4	0667	543.9	2555.1	568.7	2615.3	594.1	2676.0	620.2	2737.1	4
5	.0833	544.3	2556.1	569.1	2616.3	594.5	2677.0	620.7	2738.2	5
6	.1000	544.7	2557.1	569.5	2617.3	594.9	2678.0	621.1	2739.2	6
7	.1167	545.1	2558.1	569.9	2618.3	595.4	2679.0	621.6	2740.2	7
8	.1333	545.5	2559.1	570.3	2619.3	595.8	2680.0	622.0	2741.2	8
9	.1500	546.0	2560.1	570.8	2620.4	596.2	2681.1	622.5	2742.3	9
10	.1667	546.4	2561.1	571.2	2621.4	596.7	2682.1	622.9	2743.3	10
11	.1833	546.8	2562.1	571.6	2622.4	597.1	2683.1	623.3	2744.3	11
12	.2000	547.2	2563.1	572.0	2623.4	597.5	2684.1	623.7	2745.3	12
13	.2167	547.6	2564.1	572.4	2624.4	598.0	2685.1	624.2	2746.4	13
14	.2333	548.0	2565.1	572.8	2625.4	598.4	2686.1	624.6	2747.4	14
15	.2500	548.4	2566.1	573.3	2626.4	598.9	2687.2	625.1	2748.4	15
16	.2667	548.8	2567.1	573.7	2627.4	599.3	2688.2	625.5	2749.4	16
17	.2833	549.2	2568.1	574.1	2628.4	599.7	2689.2	626.0	2750.5	17
18	.3000	549.6	2569.1	574.5	2629.4	600.1	2690.2	626.4	2751.5	18
19	.3167	550.1	2570.1	574.9	2630.4	600.6	2691.3	626.9	2752.5	19
20	.3333	550.5	2571.1	575.3	2631.4	601.0	2692.3	627.3	2753.5	20
21	.3500	550.9	2572.1	575.8	2632.5	601.5	2693.3	627.8	2754.6	21
22	.3667	551.3	2573.1	576.2	2633.5	601.9	2694.3	628.2	2755.6	22
23	.3833	551.7	2574.1	576.6	2634.5	602.3	2695.3	628.7	2756.7	23
24	.4000	552.1	2575.1	577.0	2635.5	602.7	2696.3	629.1	2757.7	24
25	.4167	552.5	2576.1	577.5	2636.5	603.2	2697.4	629.6	2758.7	25
26	.4333	552.9	2577.1	577.9	2637.5	603.6	2698.4	630.0	2759.7	26
27	.4500	553.3	2578.1	578.3	2638.5	604.1	2699.4	630.5	2760.8	27
28	.4667	553.7	2579.1	578.7	2639.5	604.5	2700.4	630.9	2761.8	28
29	.4833	554.2	2580.1	579.2	2640.5	604.9	2701.4	631.4	2762.8	29
30	.5000	554.6	2581.1	579.6	2641.5	605.3	2702.4	631.8	2763.8	30
31	.5167	555.0	2582.1	580.0	2642.5	605.8	2703.5	632.3	2764.9	31
32	.5333	555.4	2583.1	580.4	2643.5	606.2	2704.5	632.7	2765.9	32
33	.5500	555.8	2584.1	580.9	2644.6	606.6	2705.5	633.2	2766.9	33
34	.5667	556.2	2585.1	581.3	2645.6	607.0	2706.5	633.6	2767.9	34
35	.5833	556.6	2586.2	581.7	2646.6	607.5	2707.6	634.1	2769.0	35
36	.6000	557.0	2587.2	582.1	2647.6	607.9	2708.6	634.5	2770.0	36
37	.6167	557.4	2588.2	582.6	2648.6	608.4	2709.6	634.9	2771.0	37
38	.6333	557.8	2589.2	583.0	2649.6	608.8	2710.6	635.3	2772.0	38
39	.6500	558.3	2590.2	583.4	2650.6	609.3	2711.6	635.8	2773.1	39
40	.6667	558.7	2591.2	583.8	2651.6	609.7	2712.6	636.2	2774.1	40
41	.6833	559.1	2592.2	584.3	2652.7	610.1	2713.7	636.7	2775.2	41
42	.7000	559.5	2593.2	584.7	2653.7	610.5	2714.7	637.1	2776.2	42
43	.7167	559.9	2594.2	585.1	2654.7	611.0	2715.7	637.5	2777.2	43
44	.7333	560.3	2595.2	585.5	2655.7	611.4	2716.7	638.0	2778.2	44
45	.7500	560.8	2596.2	586.0	2656.7	611.9	2717.8	638.5	2779.3	45
46	.7667	561.2	2597.2	586.4	2657.7	612.3	2718.8	638.9	2780.3	46
47	.7833	561.6	2598.2	586.8	2658.7	612.8	2719.8	639.4	2781.3	47
48	.8000	562.0	2599.2	587.2	2659.7	613.2	2720.8	639.8	2782.3	48
49	.8167	562.4	2600.2	587.7	2660.8	613.7	2721.8	640.3	2783.4	49
50	.8333	562.8	2601.2	588.1	2661.8	614.1	2722.8	640.7	2784.4	50
51	.8500	563.3	2602.2	588.5	2662.8	614.5	2723.9	641.2	2785.4	51
52	.8667	563.7	2603.2	588.9	2663.8	614.9	2724.9	641.6	2786.4	52
53	.8833	564.1	2604.2	589.4	2664.8	615.4	2725.9	642.1	2787.5	53
54	.9000	564.5	2605.2	589.8	2665.8	615.8	2726.9	642.5	2788.5	54
55	.9167	564.9	2606.2	590.2	2666.8	616.3	2728.0	643.0	2789.6	55
56	.9333	565.3	2607.2	590.6	2667.8	616.7	2729.0	643.4	2790.6	56
57	.9500	565.8	2608.3	591.1	2668.9	617.2	2730.0	643.9	2791.6	57
58	.9667	566.2	2609.3	591.5	2669.9	617.6	2731.0	644.3	2792.6	58
59	.9833	566.6	2610.3	592.0	2670.9	618.1	2732.0	644.8	2793.7	59

Use 100′ Chords up to 8° Curves
Use 50′ Chords up to 16° Curves
Use 25′ Chords up to 32° Curves
Use 10′ Chords above 32° Curves

Minutes	Dec. of Degree	52° Ext.	52° Tan.	53° Ext.	53° Tan.	54° Ext.	54° Tan.	55° Ext.	55° Tan.	Minutes
0	.0000	645.2	2794.7	672.7	2856.9	700.9	2919.5	729.9	2982.8	0
1	.0167	645.7	2795.8	673.2	2857.9	701.4	2920.6	730.4	2983.9	1
2	.0333	646.1	2796.8	673.7	2858.9	701.9	2921.6	730.9	2984.9	2
3	.0500	646.6	2797.8	674.2	2860.0	702.4	2922.7	731.4	2986.0	3
4	.0667	647.0	2798.8	674.6	2861.0	702.8	2923.8	731.9	2987.1	4
5	.0833	647.5	2799.9	675.1	2862.1	703.3	2924.9	732.4	2988.2	5
6	.1000	647.9	2800.9	675.5	2863.1	703.8	2925.9	732.9	2989.2	6
7	.1167	648.4	2802.0	676.0	2864.2	704.3	2927.0	733.4	2990.3	7
8	.1333	648.9	2803.0	676.4	2865.2	704.8	2928.0	733.8	2991.3	8
9	.1500	649.4	2804.0	676.9	2866.3	705.3	2929.1	734.3	2992.4	9
10	.1667	649.8	2805.0	677.4	2867.3	705.7	2930.1	734.8	2993.4	10
11	.1833	650.3	2806.1	677.9	2868.4	706.2	2931.2	735.3	2994.5	11
12	.2000	650.7	2807.1	678.3	2869.4	706.7	2932.2	735.8	2995.5	12
13	.2167	651.2	2808.2	678.8	2870.5	707.2	2933.3	736.3	2996.6	13
14	.2333	651.6	2809.2	679.2	2871.5	707.7	2934.3	736.8	2997.7	14
15	.2500	652.1	2810.2	679.7	2872.5	708.2	2935.4	737.3	2998.8	15
16	.2667	652.5	2811.2	680.2	2873.5	708.6	2936.4	737.8	2999.8	16
17	.2833	653.0	2812.3	680.7	2874.6	709.1	2937.5	738.2	3000.9	17
18	.3000	653.4	2813.3	681.1	2875.6	709.6	2938.5	738.7	3001.9	18
19	.3167	653.9	2814.4	681.6	2876.7	710.1	2939.6	739.2	3003.0	19
20	.3333	654.3	2815.4	682.0	2877.7	710.5	2940.6	739.7	3004.0	20
21	.3500	654.8	2816.4	682.5	2878.8	711.0	2941.7	740.2	3005.1	21
22	.3667	655.2	2817.4	683.0	2879.8	711.5	2942.7	740.7	3006.2	22
23	.3833	655.7	2818.5	683.5	2880.9	712.0	2943.8	741.2	3007.3	23
24	.4000	656.2	2819.5	683.9	2881.9	712.5	2944.8	741.7	3008.3	24
25	.4167	656.7	2820.6	684.4	2883.0	713.0	2945.9	742.2	3009.4	25
26	.4333	657.1	2821.6	684.9	2884.0	713.4	2946.9	742.7	3010.4	26
27	.4500	657.6	2822.6	685.4	2885.1	713.9	2948.0	743.2	3011.5	27
28	.4667	658.0	2823.6	685.8	2886.1	714.4	2949.0	743.7	3012.5	28
29	.4833	658.5	2824.7	686.3	2887.1	714.9	2950.1	744.2	3013.6	29
30	.5000	658.9	2825.7	686.7	2888.1	715.3	2951.1	744.7	3014.7	30
31	.5167	659.4	2826.8	687.2	2889.2	715.8	2952.2	745.2	3015.8	31
32	.5333	659.8	2827.8	687.7	2890.2	716.3	2953.2	745.7	3016.8	32
33	.5500	660.3	2828.8	688.2	2891.3	716.8	2954.3	746.2	3017.9	33
34	.5667	660.7	2829.8	688.6	2892.3	717.3	2955.3	746.7	3018.9	34
35	.5833	661.2	2830.9	689.1	2893.4	717.8	2956.4	747.2	3020.0	35
36	.6000	661.6	2831.9	689.6	2894.4	718.2	2957.5	747.7	3021.1	36
37	.6167	662.1	2833.0	690.1	2895.5	718.7	2958.6	748.2	3022.1	37
38	.6333	662.5	2834.0	690.5	2896.5	719.2	2959.6	748.7	3023.2	38
39	.6500	663.0	2835.1	691.0	2897.6	719.7	2960.7	749.2	3024.3	39
40	.6667	663.5	2836.1	691.5	2898.6	720.2	2961.7	749.7	3025.3	40
41	.6833	664.0	2837.2	692.0	2899.7	720.7	2962.8	750.2	3026.4	41
42	.7000	664.4	2838.2	692.4	2900.7	721.1	2963.8	750.7	3027.5	42
43	.7167	664.9	2839.2	692.9	2901.8	721.6	2964.9	751.2	3028.6	43
44	.7333	665.3	2840.2	693.4	2902.8	722.1	2965.9	751.7	3029.6	44
45	.7500	665.8	2841.3	693.9	2903.9	722.6	2967.0	752.2	3030.7	45
46	.7667	666.2	2842.3	694.3	2904.9	723.1	2968.0	752.6	3031.7	46
47	.7833	666.7	2843.4	694.8	2906.0	723.6	2969.1	753.1	3032.8	47
48	.8000	667.2	2844.4	695.3	2907.0	724.1	2970.1	753.6	3033.8	48
49	.8167	667.7	2845.5	695.8	2908.1	724.6	2971.2	754.1	3035.0	49
50	.8333	668.1	2846.5	696.2	2909.1	725.0	2972.2	754.6	3036.0	50
51	.8500	668.6	2847.5	696.7	2910.2	725.5	2973.3	755.1	3037.1	51
52	.8667	669.0	2848.5	697.1	2911.2	726.0	2974.4	755.6	3038.1	52
53	.8833	669.5	2849.6	697.6	2912.3	726.5	2975.5	756.1	3039.2	53
54	.9000	669.9	2850.6	698.1	2913.3	727.0	2976.5	756.6	3040.2	54
55	.9167	670.4	2851.7	698.6	2914.4	727.5	2977.6	757.1	3041.3	55
56	.9333	670.9	2852.7	699.0	2915.4	728.0	2978.6	757.6	3042.4	56
57	.9500	671.4	2853.8	699.5	2916.5	728.5	2979.7	758.1	3043.5	57
58	.9667	671.8	2854.8	700.0	2917.5	729.0	2980.7	758.6	3044.5	58
59	.9833	672.3	2855.9	700.5	2918.5	729.5	2981.8	759.1	3045.6	59

Use 100′ Chords up to 8° Curves Use 25′ Chords up to 32° Curves
Use 50′ Chords up to 16° Curves Use 10′ Chords above 32° Curves

Minutes	Dec. of Degree	56° Ext.	56° Tan.	57° Ext.	57° Tan.	58° Ext.	58° Tan.	59° Ext.	59° Tan.	Minutes
0	.0000	759.6	3046.6	790.2	3111.1	821.4	3176.1	853.5	3241.9	0
1	.0167	760.1	3047.7	790.7	3112.2	821.9	3177.2	854.0	3243.0	1
2	.0333	760.6	3048.8	791.2	3113.3	822.5	3178.3	854.6	3244.1	2
3	.0500	761.1	3049.9	791.7	3114.4	823.0	3179.4	855.1	3245.2	3
4	.0667	761.6	3050.9	792.2	3115.4	823.5	3180.5	855.7	3246.3	4
5	.0833	762.2	3052.0	792.8	3116.5	824.1	3181.6	856.2	3247.4	5
6	.1000	762.7	3053.1	793.3	3117.6	824.6	3182.7	856.8	3248.5	6
7	.1167	763.2	3054.2	793.8	3118.7	825.2	3183.8	857.3	3249.6	7
8	.1333	763.7	3055.2	794.3	3119.7	825.7	3184.9	857.9	3250.7	8
9	.1500	764.2	3056.3	794.8	3120.8	826.2	3186.0	858.5	3251.8	9
10	.1667	764.7	3057.4	795.3	3121.9	826.7	3187.1	859.0	3252.9	10
11	.1833	765.2	3058.5	795.8	3123.0	827.3	3188.2	859.5	3254.0	11
12	.2000	765.7	3059.5	796.3	3124.1	827.8	3189.2	860.0	3255.1	12
13	.2167	766.2	3060.6	796.9	3125.2	828.4	3190.3	860.6	3256.2	13
14	.2333	766.7	3061.6	797.4	3126.2	828.9	3191.4	861.1	3257.3	14
15	.2500	767.2	3062.7	797.9	3127.3	829.4	3192.5	861.7	3258.4	15
16	.2667	767.7	3063.8	798.4	3128.4	829.9	3193.6	862.2	3259.5	16
17	.2833	768.2	3064.9	798.9	3129.5	830.5	3194.7	862.8	3260.6	17
18	.3000	768.7	3065.9	799.4	3130.6	831.0	3195.8	863.3	3261.7	18
19	.3167	769.2	3067.0	799.9	3131.7	831.5	3196.9	863.8	3262.8	19
20	.3333	769.7	3068.1	800.5	3132.7	832.1	3198.0	864.4	3263.9	20
21	.3500	770.3	3069.2	801.0	3133.8	832.5	3199.1	864.9	3265.0	21
22	.3667	770.8	3070.2	801.5	3134.9	833.1	3200.2	865.5	3266.1	22
23	.3833	771.3	3071.3	802.0	3136.0	833.6	3201.3	866.0	3267.2	23
24	.4000	771.8	3072.4	802.5	3137.0	834.2	3202.4	866.6	3268.3	24
25	.4167	772.3	3073.5	803.1	3138.1	834.7	3203.5	867.1	3269.4	25
26	.4333	772.8	3074.5	803.6	3139.2	835.3	3204.5	867.7	3270.5	26
27	.4500	773.3	3075.6	804.2	3140.3	835.8	3205.6	868.2	3271.6	27
28	.4667	773.8	3076.6	804.7	3141.4	836.3	3206.7	868.8	3272.7	28
29	.4833	774.3	3077.7	805.2	3142.5	836.8	3207.8	869.3	3273.8	29
30	.5000	774.8	3078.8	805.7	3143.5	837.4	3208.9	869.9	3274.9	30
31	.5167	775.3	3079.9	806.3	3144.6	837.8	3210.0	870.5	3276.0	31
32	.5333	775.8	3080.9	806.8	3145.7	838.4	3211.1	871.0	3277.1	32
33	.5500	776.3	3082.0	807.3	3146.8	838.9	3212.2	871.6	3278.2	33
34	.5667	776.8	3083.1	807.8	3147.9	839.5	3213.3	872.1	3279.4	34
35	.5833	777.3	3084.2	808.3	3149.0	840.0	3214.4	872.7	3280.5	35
36	.6000	777.8	3085.2	808.8	3150.0	840.6	3215.5	873.2	3281.6	36
37	.6167	778.4	3086.3	809.4	3151.1	841.1	3216.6	873.8	3282.7	37
38	.6333	778.9	3087.4	809.9	3152.2	841.6	3217.7	874.3	3283.8	38
39	.6500	779.4	3088.5	810.4	3153.3	842.1	3218.8	874.9	3284.9	39
40	.6667	779.9	3089.6	810.9	3154.4	842.7	3219.9	875.4	3286.0	40
41	.6833	780.4	3090.7	811.5	3155.5	843.1	3221.0	876.0	3287.1	41
42	.7000	780.9	3091.7	812.0	3156.6	843.8	3222.1	876.5	3288.2	42
43	.7167	781.4	3092.8	812.5	3157.7	844.2	3223.2	877.0	3289.3	43
44	.7333	781.9	3093.9	813.0	3158.7	844.9	3224.3	877.6	3290.5	44
45	.7500	782.5	3095.0	813.6	3159.8	845.5	3225.4	878.1	3291.6	45
46	.7667	783.0	3096.0	814.1	3160.9	846.0	3226.5	878.7	3292.7	46
47	.7833	783.5	3097.1	814.6	3162.0	846.5	3227.6	879.2	3293.8	47
48	.8000	784.0	3098.2	815.1	3163.1	847.0	3228.7	879.8	3294.9	48
49	.8167	784.5	3099.3	815.7	3164.2	847.6	3229.8	880.3	3296.0	49
50	.8333	785.0	3100.3	816.2	3165.3	848.1	3230.9	880.9	3297.1	50
51	.8500	785.5	3101.4	816.7	3166.4	848.7	3232.0	881.5	3298.2	51
52	.8667	786.0	3102.5	817.2	3167.4	849.2	3233.1	882.0	3299.3	52
53	.8833	786.6	3103.6	817.8	3168.5	849.8	3234.2	882.6	3300.4	53
54	.9000	787.1	3104.6	818.3	3169.6	850.3	3235.3	883.1	3301.5	54
55	.9167	787.6	3105.7	818.8	3170.7	850.9	3236.4	883.7	3302.6	55
56	.9333	788.1	3106.8	819.3	3171.8	851.4	3237.5	884.2	3303.8	56
57	.9500	788.6	3107.9	819.9	3172.9	852.0	3238.6	884.8	3304.9	57
58	.9667	789.1	3108.9	820.4	3174.0	852.5	3239.7	885.3	3306.0	58
59	.9833	789.7	3110.0	820.9	3175.1	853.0	3240.8	885.9	3307.1	59

Use 100′ Chords up to 8° Curves
Use 50′ Chords up to 16° Curves
Use 25′ Chords up to 32° Curves
Use 10′ Chords above 32° Curves

Minutes	Dec. of Degree	60°		61°		62°		63°		Minutes
		Ext.	Tan.	Ext.	Tan.	Ext.	Tan.	Ext.	Tan.	
0	.0000	886.4	3308.2	920.2	3375.2	954.8	3442.9	990.3	3511.3	0
1	.0167	886.9	3309.3	920.8	3376.3	955.4	3444.1	990.9	3512.4	1
2	.0333	887.5	3310.4	921.4	3377.4	956.0	3445.2	991.5	3513.6	2
3	.0500	888.1	3311.5	922.0	3378.5	956.6	3446.3	992.1	3514.8	3
4	.0667	888.7	3312.7	922.5	3379.7	957.2	3447.5	992.7	3515.9	4
5	.0833	889.3	3313.8	923.0	3380.8	957.7	3448.6	993.3	3517.1	5
6	.1000	889.8	3314.9	923.6	3381.9	958.3	3449.7	993.9	3518.2	6
7	.1167	890.3	3316.0	924.2	3383.1	958.9	3450.9	994.5	3519.3	7
8	.1333	890.9	3317.1	924.8	3384.2	959.5	3452.0	995.1	3520.5	8
9	.1500	891.5	3318.2	925.3	3385.3	960.1	3453.2	995.7	3521.6	9
10	.1667	892.0	3319.3	925.9	3386.4	960.7	3454.3	996.3	3522.8	10
11	.1833	892.6	3320.5	926.5	3387.5	961.3	3455.4	996.9	3524.0	11
12	.2000	893.1	3321.6	927.1	3388.7	961.9	3456.6	997.5	3525.1	12
13	.2167	893.7	3322.7	927.6	3389.8	962.4	3457.7	998.1	3526.2	13
14	.2333	894.3	3323.8	928.2	3390.9	963.0	3458.8	998.7	3527.4	14
15	.2500	894.8	3324.9	928.7	3392.1	963.6	3460.0	999.3	3528.6	15
16	.2667	895.4	3326.0	929.3	3393.2	964.2	3461.1	999.9	3529.7	16
17	.2833	895.9	3327.1	929.9	3394.3	964.8	3462.3	1000.5	3530.9	17
18	.3000	896.5	3328.3	930.5	3395.4	965.4	3463.4	1001.1	3532.0	18
19	.3167	897.0	3329.4	931.0	3396.6	966.0	3464.6	1001.7	3533.1	19
20	.3333	897.6	3330.5	931.6	3397.7	966.6	3465.7	1002.3	3534.3	20
21	.3500	898.2	3331.6	932.2	3398.8	967.2	3466.8	1002.9	3535.4	21
22	.3667	898.8	3332.7	932.8	3399.9	967.8	3467.9	1003.5	3536.6	22
23	.3833	899.3	3333.8	933.3	3401.1	968.3	3469.0	1004.1	3537.8	23
24	.4000	899.9	3334.9	933.9	3402.2	968.9	3470.2	1004.7	3538.9	24
25	.4167	900.5	3336.1	934.5	3403.3	969.5	3471.3	1005.3	3540.0	25
26	.4333	901.0	3337.2	935.1	3404.4	970.1	3472.5	1005.9	3541.2	26
27	.4500	901.6	3338.3	935.7	3405.6	970.7	3473.6	1006.5	3542.3	27
28	.4667	902.1	3339.4	936.3	3406.7	971.3	3474.7	1007.1	3543.5	28
29	.4833	902.7	3340.5	936.8	3407.8	971.9	3475.9	1007.8	3544.6	29
30	.5000	903.2	3341.6	937.4	3408.9	972.5	3477.0	1008.4	3545.8	30
31	.5167	903.8	3342.7	938.0	3410.1	973.0	3478.1	1009.0	3546.9	31
32	.5333	904.4	3343.9	938.6	3411.2	973.6	3479.3	1009.6	3548.1	32
33	.5500	904.9	3345.0	939.1	3412.3	974.2	3480.5	1010.2	3549.2	33
34	.5667	905.5	3346.1	939.7	3413.5	974.8	3481.6	1010.8	3550.4	34
35	.5833	906.1	3347.2	940.4	3414.6	975.4	3482.7	1011.4	3551.6	35
36	.6000	906.6	3348.3	940.9	3415.7	976.0	3483.9	1012.0	3552.7	36
37	.6167	907.2	3349.5	941.5	3416.8	976.6	3485.0	1012.6	3553.8	37
38	.6333	907.7	3350.6	942.1	3418.0	977.2	3486.2	1013.2	3555.0	38
39	.6500	908.2	3351.7	942.6	3419.2	977.8	3487.4	1013.9	3556.2	39
40	.6667	908.8	3352.8	943.2	3420.3	978.4	3488.5	1014.5	3557.3	40
41	.6833	909.4	3353.9	943.8	3421.4	979.0	3489.6	1015.1	3558.4	41
42	.7000	910.0	3355.0	944.4	3422.5	979.6	3490.7	1015.7	3559.6	42
43	.7167	910.6	3356.1	944.9	3423.6	980.2	3491.9	1016.3	3560.8	43
44	.7333	911.1	3357.3	945.5	3424.8	980.8	3493.0	1016.9	3562.0	44
45	.7500	911.7	3358.4	946.1	3426.0	981.4	3494.2	1017.5	3563.2	45
46	.7667	912.3	3359.5	946.7	3427.1	982.0	3495.3	1018.1	3564.3	46
47	.7833	912.8	3360.6	947.2	3428.2	982.6	3496.4	1018.7	3565.5	47
48	.8000	913.4	3361.8	947.8	3429.3	983.2	3497.6	1019.3	3566.6	48
49	.8167	913.9	3362.9	948.4	3430.4	983.8	3498.7	1020.0	3567.7	49
50	.8333	914.5	3364.0	949.0	3431.6	984.4	3499.9	1020.6	3568.9	50
51	.8500	915.1	3365.1	949.6	3432.8	984.9	3501.0	1021.2	3570.0	51
52	.8667	915.7	3366.2	950.2	3433.6	985.5	3502.2	1021.8	3571.2	52
53	.8833	916.2	3367.3	950.7	3434.0	986.1	3503.3	1022.4	3572.3	53
54	.9000	916.8	3368.5	951.3	3436.1	986.7	3504.5	1023.0	3573.5	54
55	.9167	917.4	3369.6	951.9	3437.2	987.3	3505.6	1023.6	3574.6	55
56	.9333	918.0	3370.7	952.5	3438.4	987.9	3506.8	1024.2	3575.8	56
57	.9500	918.6	3371.9	953.0	3439.6	988.5	3507.9	1024.8	3576.9	57
58	.9667	919.1	3373.0	953.6	3440.7	989.1	3509.0	1025.4	3578.1	58
59	.9833	919.6	3374.1	954.2	3441.8	989.7	3510.1	1026.1	3579.3	59

Use 100′ Chords up to 8° Curves Use 25′ Chords up to 32° Curves
Use 50′ Chords up to 16° Curves Use 10′ Chords above 32° Curves

Minutes	Dec. of Degree	64° Ext.	64° Tan.	65° Ext.	65° Tan.	66° Ext.	66° Tan	67° Ext.	67° Tan.	Minutes
0	.0000	1026.7	3580.4	1064.0	3650.4	1102.2	3721.1	1141.5	3792.6	0
1	.0167	1027.3	3581.6	1064.6	3651.6	1102.9	3722.3	1142.2	3793.8	1
2	.0333	1027.9	3582.8	1065.2	3652.8	1103.5	3723.4	1142.8	3795.0	2
3	.0500	1028.6	3583.9	1065.9	3654.0	1104.2	3724.6	1143.5	3796.2	3
4	.0667	1029.2	3585.1	1066.5	3655.1	1104.8	3725.8	1144.1	3797.4	4
5	.0833	1029.8	3586.3	1067.1	3656.3	1105.5	3727.0	1144.8	3798.6	5
6	.1000	1030.4	3587.4	1067.7	3657.5	1106.1	3728.2	1145.4	3799.8	6
7	.1167	1031.1	3588.6	1068.4	3658.6	1106.8	3729.4	1146.1	3801.0	7
8	.1333	1031.7	3589.7	1069.0	3659.8	1107.4	3730.6	1146.7	3802.2	8
9	.1500	1032.3	3590.9	1069.6	3661.0	1108.1	3731.7	1147.4	3803.4	9
10	.1667	1032.9	3592.1	1070.2	3662.2	1108.7	3732.9	1148.1	3804.6	10
11	.1833	1033.5	3593.3	1070.9	3663.4	1109.4	3734.1	1148.8	3805.8	11
12	.2000	1034.1	3594.4	1071.5	3664.5	1110.0	3735.3	1149.4	3807.0	12
13	.2167	1034.8	3595.5	1072.1	3665.7	1110.7	3736.5	1150.1	3808.2	13
14	.2333	1035.4	3596.7	1072.7	3666.9	1111.3	3737.7	1150.7	3809.4	14
15	.2500	1036.0	3597.9	1073.4	3668.0	1112.0	3738.9	1151.4	3810.6	15
16	.2667	1036.6	3599.1	1074.0	3669.2	1112.6	3740.1	1152.0	3811.8	16
17	.2833	1037.3	3600.3	1074.6	3670.4	1113.3	3741.3	1152.7	3813.0	17
18	.3000	1037.9	3601.4	1075.2	3671.6	1113.9	3742.4	1153.3	3814.2	18
19	.3167	1038.5	3602.6	1075.9	3672.8	1114.6	3743.6	1154.0	3815.4	19
20	.3333	1039.1	3603.7	1076.6	3673.9	1115.2	3744.8	1154.7	3816.6	20
21	.3500	1039.7	3604.8	1077.2	3675.0	1115.9	3746.0	1155.4	3817.8	21
22	.3667	1040.3	3606.0	1077.8	3676.2	1116.5	3747.2	1156.0	3819.0	22
23	.3833	1041.0	3607.2	1078.5	3677.4	1117.2	3748.4	1156.7	3820.2	23
24	.4000	1041.6	3608.4	1079.1	3678.6	1117.8	3749.6	1157.4	3821.4	24
25	.4167	1042.2	3609.5	1079.8	3679.7	1118.5	3750.7	1158.1	3822.6	25
26	.4333	1042.8	3610.7	1080.4	3680.9	1119.1	3751.9	1158.7	3823.8	26
27	.4500	1043.5	3611.9	1081.1	3682.1	1119.8	3753.1	1159.4	3825.0	27
28	.4667	1044.1	3613.0	1081.7	3683.3	1120.4	3754.3	1160.1	3826.2	28
29	.4833	1044.7	3614.1	1082.4	3684.5	1121.1	3755.5	1160.8	3827.4	29
30	.5000	1045.3	3615.3	1083.0	3685.6	1121.7	3756.7	1161.4	3828.6	30
31	.5167	1045.9	3616.5	1083.6	3686.8	1122.3	3757.9	1162.1	3829.8	31
32	.5333	1046.5	3617.7	1084.2	3688.0	1123.0	3759.1	1162.8	3831.0	32
33	.5500	1047.2	3618.9	1084.9	3689.2	1123.7	3760.3	1163.5	3832.2	33
34	.5667	1047.8	3620.0	1085.5	3690.4	1124.3	3761.5	1164.1	3833.4	34
35	.5833	1048.4	3621.1	1086.2	3691.6	1125.0	3762.7	1164.8	3834.6	35
36	.6000	1049.0	3622.3	1086.8	3692.7	1125.6	3763.9	1165.5	3835.9	36
37	.6167	1049.7	3623.5	1087.5	3693.9	1126.3	3765.1	1166.2	3837.1	37
38	.6333	1050.3	3624.7	1088.1	3695.1	1126.9	3766.3	1166.8	3838.3	38
39	.6500	1050.9	3625.8	1088.8	3696.2	1127.6	3767.5	1167.5	3839.5	39
40	.6667	1051.5	3627.0	1089.4	3697.4	1128.3	3768.7	1168.2	3840.7	40
41	.6833	1052.1	3628.2	1090.0	3698.6	1129.0	3769.9	1168.9	3841.9	41
42	.7000	1052.7	3629.4	1090.6	3699.8	1129.6	3771.0	1169.5	3843.1	42
43	.7167	1053.4	3630.5	1091.3	3701.0	1130.3	3772.2	1170.2	3844.3	43
44	.7333	1054.0	3631.7	1091.9	3702.2	1130.9	3773.4	1170.9	3845.5	44
45	.7500	1054.6	3632.8	1092.6	3703.3	1131.6	3774.6	1171.6	3846.7	45
46	.7667	1055.2	3634.0	1093.2	3704.5	1132.2	3775.8	1172.2	3847.9	46
47	.7833	1055.9	3635.2	1093.9	3705.7	1132.9	3777.0	1172.9	3849.1	47
48	.8000	1056.5	3636.4	1094.5	3706.9	1133.5	3778.2	1173.6	3850.4	48
49	.8167	1057.1	3637.5	1095.2	3708.1	1134.2	3779.4	1174.3	3851.6	49
50	.8333	1057.7	3638.7	1095.8	3709.3	1134.9	3780.6	1174.9	3852.8	50
51	.8500	1058.4	3639.9	1096.4	3710.5	1135.6	3781.8	1175.6	3854.0	51
52	.8667	1059.0	3641.1	1097.0	3711.6	1136.2	3783.0	1176.3	3855.2	52
53	.8833	1059.6	3642.3	1097.7	3712.8	1136.9	3784.2	1177.0	3856.4	53
54	.9000	1060.2	3643.4	1098.3	3714.0	1137.5	3785.4	1177.6	3857.6	54
55	.9167	1060.9	3644.6	1099.0	3715.1	1138.2	3786.6	1178.3	3858.8	55
56	.9333	1061.5	3645.7	1099.6	3716.3	1138.8	3787.8	1179.0	3860.0	56
57	.9500	1062.1	3646.9	1100.3	3717.5	1139.5	3789.0	1179.7	3861.2	57
58	.9667	1062.7	3648.1	1100.9	3718.7	1140.1	3790.2	1180.3	3862.5	58
59	.9833	1063.4	3649.2	1101.6	3719.9	1140.8	3791.4	1181.0	3863.7	59

Use 100′ Chords up to 8° Curves
Use 50′ Chords up to 16° Curves
Use 25′ Chords up to 32° Curves
Use 10′ Chords above 32° Curves

Minutes	Dec. of Degree	68°		69°		70°		71°		Minutes
		Ext.	Tan.	Ext.	Tan.	Ext.	Tan.	Ext.	Tan.	
0	.0000	1181.6	3864.9	1222.9	3938.1	1265.0	4012.1	1308.4	4087.1	0
1	.0167	1182.3	3866.1	1223.6	3939.4	1265.7	4013.4	1309.2	4088.4	1
2	.0333	1183.0	3867.3	1224.3	3940.6	1266.4	4014.6	1309.9	4089.7	2
3	.0500	1183.7	3868.5	1225.0	3941.8	1267.2	4015.9	1310.6	4091.0	3
4	.0667	1184.4	3869.7	1225.7	3943.0	1267.9	4017.1	1311.3	4092.2	4
5	.0833	1185.1	3870.9	1226.4	3944.2	1268.6	4018.4	1312.1	4093.5	5
6	.1000	1185.7	3872.2	1227.1	3945.5	1269.3	4019.6	1312.8	4094.7	6
7	.1167	1186.4	3873.4	1227.8	3946.7	1270.1	4020.8	1313.5	4096.0	7
8	.1333	1187.1	3874.6	1228.5	3947.9	1270.8	4022.1	1314.2	4097.2	8
9	.1500	1187.8	3875.8	1229.2	3949.2	1271.5	4023.4	1315.0	4098.5	9
10	.1667	1188.5	3877.0	1229.9	3950.4	1272.2	4024.6	1315.7	4099.8	10
11	.1833	1189.2	3878.2	1230.6	3951.6	1272.9	4025.8	1316.5	4101.1	11
12	.2000	1189.8	3879.5	1231.3	3952.9	1273.6	4027.1	1317.2	4102.3	12
13	.2167	1190.5	3880.7	1232.0	3954.1	1274.4	4028.4	1317.9	4103.6	13
14	.2333	1191.2	3881.9	1232.7	3955.3	1275.1	4029.6	1318.6	4104.8	14
15	.2500	1191.9	3883.1	1233.4	3956.6	1275.8	4030.8	1319.4	4106.1	15
16	.2667	1192.6	3884.3	1234.1	3957.8	1276.5	4032.1	1320.1	4107.3	16
17	.2833	1193.3	3885.6	1234.8	3959.0	1277.3	4033.4	1320.8	4108.6	17
18	.3000	1193.9	3886.8	1235.5	3960.2	1278.0	4034.6	1321.5	4109.8	18
19	.3167	1194.6	3888.0	1236.2	3961.5	1278.7	4035.9	1322.3	4111.1	19
20	.3333	1195.3	3889.2	1236.9	3962.7	1279.4	4037.1	1323.0	4112.4	20
21	.3500	1196.0	3890.4	1237.6	3964.0	1280.1	4038.4	1323.7	4113.7	21
22	.3667	1196.7	3891.6	1238.3	3965.2	1280.8	4039.6	1324.4	4114.9	22
23	.3833	1197.4	3892.9	1239.0	3966.4	1281.6	4040.9	1325.2	4116.2	23
24	.4000	1198.0	3894.1	1239.7	3967.6	1282.3	4042.1	1325.9	4117.4	24
25	.4167	1198.7	3895.3	1240.4	3968.9	1283.0	4043.4	1326.7	4118.7	25
26	.4333	1199.4	3896.5	1241.1	3970.1	1283.7	4044.6	1327.4	4119.9	26
27	.4500	1200.1	3897.7	1241.8	3971.3	1284.5	4045.9	1328.2	4121.2	27
28	.4667	1200.8	3898.9	1242.5	3972.5	1285.2	4047.1	1228.9	4122.4	28
29	.4833	1201.5	3900.2	1243.2	3973.8	1285.9	4048.4	1329.7	4123.7	29
30	.5000	1202.1	3901.4	1243.9	3975.0	1286.6	4049.6	1330.4	4125.0	30
31	.5167	1202.8	3902.6	1244.6	3976.3	1287.3	4050.9	1331.1	4126.3	31
32	.5333	1203.5	3903.8	1245.3	3977.5	1288.0	4052.1	1331.8	4127.5	32
33	.5500	1204.2	3905.0	1246.0	3978.8	1288.8	4053.4	1332.6	4128.7	33
34	.5667	1204.9	3906.3	1246.7	3980.0	1289.5	4054.6	1333.3	4130.0	34
35	.5833	1205.6	3907.5	1247.4	3981.2	1290.2	4055.9	1334.1	4131.5	35
36	.6000	1206.2	3908.7	1248.1	3982.4	1290.9	4057.1	1334.8	4132.6	36
37	.6167	1206.9	3909.9	1248.8	3983.7	1291.7	4058.4	1335.6	4133.9	37
38	.6333	1207.6	3911.2	1249.5	3984.9	1292.4	4059.6	1336.3	4135.1	38
39	.6500	1208.3	3912.4	1250.2	3986.1	1293.1	4060.9	1337.1	4136.4	39
40	.6667	1209.0	3913.6	1250.9	3987.4	1293.8	4062.1	1337.8	4137.7	40
41	.6833	1209.7	3914.9	1251.6	3988.7	1294.6	4063.4	1338.5	4139.0	41
42	.7000	1210.3	3916.1	1252.3	3989.9	1295.3	4064.6	1339.2	4140.2	42
43	.7167	1211.0	3917.3	1253.0	3991.1	1296.0	4065.9	1340.0	4141.5	43
44	.7333	1211.7	3918.5	1253.7	3992.3	1296.7	4067.1	1340.7	4142.7	44
45	.7500	1212.4	3919.8	1254.4	3993.6	1297.5	4068.4	1341.5	4144.0	45
46	.7667	1213.1	3921.0	1255.1	3994.8	1298.2	4069.6	1342.2	4145.3	46
47	.7833	1213.8	3922.2	1255.8	3996.0	1298.9	4070.9	1343.0	4146.6	47
48	.8000	1214.5	3923.4	1256.5	3997.3	1299.6	4072.1	1343.7	4147.8	48
49	.8167	1215.2	3924.7	1257.2	3998.6	1300.4	4073.4	1344.5	4149.1	49
50	.8333	1215.9	3925.9	1257.9	3999.8	1301.1	4074.6	1345.2	4150.4	50
51	.8500	1216.6	3927.1	1258.6	4001.0	1301.9	4075.9	1346.0	4151.7	51
52	.8667	1217.3	3928.3	1259.3	4002.2	1302.6	4077.1	1346.7	4152.9	52
53	.8833	1218.0	3929.6	1260.0	4003.4	1303.3	4078.4	1347.5	4154.2	53
54	.9000	1218.7	3930.8	1260.7	4004.7	1304.0	4079.6	1348.2	4155.4	54
55	.9167	1219.4	3932.0	1261.4	4006.0	1304.8	4080.9	1349.0	4156.7	55
56	.9333	1220.1	3933.2	1262.1	4007.2	1305.5	4082.1	1349.7	4158.0	56
57	9500	1220.8	3934.4	1262.8	4008.5	1306.2	4083.4	1350.5	4159.3	57
58	.9667	1221.5	3935.7	1263.5	4009.7	1306.9	4084.6	1351.2	4160.5	58
59	.9833	1222.2	3936.9	1264.3	4010.9	1307.7	4085.9	1352.0	4161.8	59

Use 100′ Chords up to 8° Curves Use 25′ Chords up to 32° Curves
Use 50′ Chords up to 16° Curves Use 10′ Chords above 32° Curves

Minutes	Dec. of Degree	72°		73°		74°		75°		Minutes
		Ext.	Tan.	Ext.	Tan.	Ext.	Tan.	Ext.	Tan.	
0	.0000	1352.7	4163.1	1398.1	4240.0	1444.7	4317.8	1492.5	4396.7	0
1	.0167	1353.5	4164.4	1398.9	4241.3	1445.5	4319.2	1493.3	4398.1	1
2	.0333	1354.2	4165.6	1399.6	4242.6	1446.2	4320.5	1494.1	4399.4	2
3	.0500	1355.0	4166.9	1400.4	4243.9	1447.0	4321.8	1494.9	4400.8	3
4	.0667	1355.7	4168.2	1401.2	4245.1	1447.8	4323.1	1495.7	4402.1	4
5	.0833	1356.5	4169.5	1402.0	4246.4	1448.6	4324.4	1496.5	4403.4	5
6	.1000	1357.2	4170.7	1402.7	4247.7	1449.4	4325.7	1497.3	4404.7	6
7	.1167	1358.0	4172.0	1403.5	4249.0	1450.2	4327.0	1498.2	4406.1	7
8	.1333	1358.7	4173.3	1404.2	4250.3	1451.0	4328.3	1499.0	4407.4	8
9	.1500	1359.5	4174.5	1405.0	4251.6	1451.8	4329.6	1499.8	4408.7	9
10	.1667	1360.2	4175.8	1405.8	4252.9	1452.6	4330.9	1500.6	4410.0	10
11	.1833	1361.0	4177.1	1406.6	4254.2	1453.4	4332.3	1501.4	4411.4	11
12	.2000	1361.7	4178.4	1407.3	4255.5	1454.1	4333.6	1502.2	4412.7	12
13	.2167	1362.5	4179.7	1408.1	4256.8	1454.9	4334.9	1503.0	4414.0	13
14	.2333	1363.2	4181.0	1408.8	4258.1	1455.7	4336.2	1503.8	4415.3	14
15	.2500	1364.0	4182.3	1409.6	4259.4	1456.5	4337.5	1504.6	4416.6	15
16	.2667	1364.7	4183.5	1410.4	4260.7	1457.3	4338.8	1505.4	4418.0	16
17	.2833	1365.5	4184.8	1411.2	4262.0	1458.1	4340.1	1506.2	4419.4	17
18	.3000	1366.2	4186.1	1411.9	4263.2	1458.9	4341.4	1507.0	4420.7	18
19	.3167	1367.0	4187.4	1412.7	4264.5	1459.7	4342.7	1507.9	4422.0	19
20	.3333	1367.7	4188.6	1413.5	4265.8	1460.5	4344.0	1508.7	4423.3	20
21	.3500	1368.5	4189.9	1414.3	4267.1	1461.3	4345.4	1509.5	4424.6	21
22	.3667	1369.2	4191.2	1415.1	4268.4	1462.0	4346.7	1510.3	4426.0	22
23	.3833	1370.0	4192.5	1415.9	4269.7	1462.8	4348.0	1511.2	4427.3	23
24	.4000	1370.7	4193.7	1416.6	4271.0	1463.6	4349.3	1512.0	4428.6	24
25	.4167	1371.5	4195.0	1417.4	4272.3	1464.4	4350.6	1512.8	4430.0	25
26	.4333	1372.2	4196.3	1418.2	4273.6	1465.2	4351.9	1513.6	4431.3	26
27	.4500	1373.0	4197.6	1419.0	4274.9	1466.0	4353.2	1514.5	4432.7	27
28	.4667	1373.7	4198.8	1419.7	4276.2	1466.8	4354.5	1515.3	4434.0	28
29	.4833	1374.5	4200.1	1420.5	4277.5	1467.6	4355.8	1516.1	4435.3	29
30	.5000	1375.2	4201.4	1421.3	4278.8	1468.4	4357.1	1516.9	4436.6	30
31	.5167	1376.0	4202.7	1422.1	4280.1	1469.2	4358.5	1517.7	4438.0	31
32	.5333	1376.7	4204.0	1422.9	4281.4	1469.9	4359.8	1518.5	4439.3	32
33	.5500	1377.5	4205.3	1423.7	4282.7	1470.7	4361.1	1519.4	4440.7	33
34	.5667	1378.2	4206.5	1424.4	4284.0	1471.5	4362.4	1520.2	4442.0	34
35	.5833	1379.0	4207.8	1425.2	4285.3	1472.3	4363.8	1521.0	4443.3	35
36	.6000	1379.7	4209.1	1426.0	4286.6	1473.1	4365.1	1521.8	4444.6	36
37	.6167	1380.5	4210.4	1426.8	4287.9	1473.9	4366.4	1522.7	4446.0	37
38	.6333	1381.2	4211.7	1427.5	4289.2	1474.7	4367.7	1523.5	4447.3	38
39	.6500	1382.0	4213.0	1428.3	4290.5	1475.6	4369.0	1524.3	4448.7	39
40	.6667	1382.8	4214.3	1429.1	4291.8	1476.4	4370.3	1525.1	4450.0	40
41	.6833	1383.6	4215.6	1429.9	4293.1	1477.2	4371.7	1525.9	4451.4	41
42	.7000	1384.3	4216.8	1430.7	4294.4	1478.0	4373.0	1526.7	4452.7	42
43	.7167	1385.1	4218.1	1431.5	4295.7	1478.8	4374.3	1527.6	4454.0	43
44	.7333	1385.8	4219.4	1432.2	4297.0	1479.6	4375.6	1528.4	4455.3	44
45	.7500	1386.6	4220.7	1433.0	4298.3	1480.4	4377.0	1529.2	4456.7	45
46	.7667	1387.4	4222.0	1433.8	4299.6	1481.2	4378.3	1530.0	4458.0	46
47	.7833	1388.2	4223.3	1434.6	4300.9	1482.0	4379.6	1530.9	4459.4	47
48	.8000	1388.9	4224.5	1435.3	4302.2	1482.8	4380.9	1531.7	4460.7	48
49	.8167	1389.7	4225.8	1436.1	4303.5	1483.6	4382.2	1532.5	4462.1	49
50	.8333	1390.4	4227.1	1436.9	4304.8	1484.4	4383.5	1533.3	4463.4	50
51	.8500	1391.2	4228.4	1437.7	4306.1	1485.2	4384.9	1534.1	4464.7	51
52	.8667	1392.0	4229.7	1438.5	4307.4	1486.0	4386.2	1534.9	4466.0	52
53	.8833	1392.8	4231.0	1439.3	4308.7	1486.9	4387.5	1535.8	4467.4	53
54	.9000	1393.5	4232.3	1440.0	4310.0	1487.7	4388.8	1536.6	4468.7	54
55	.9167	1394.3	4233.6	1440.8	4311.3	1488.5	4390.2	1537.4	4470.1	55
56	.9333	1395.0	4234.8	1441.6	4312.6	1489.3	4391.5	1538.2	4471.4	56
57	.9500	1395.8	4236.1	1442.4	4313.9	1490.1	4392.8	1539.1	4472.7	57
58	.9667	1396.6	4237.4	1443.1	4315.2	1490.9	4394.1	1539.9	4474.1	58
59	.9833	1397.4	4238.7	1443.9	4316.5	1491.7	4395.4	1540.7	4475.4	59

Use 100′ Chords up to 8° Curves
Use 50′ Chords up to 16° Curves
Use 25′ Chords up to 32° Curves
Use 10′ Chords above 32° Curves

Minutes	Dec. of Degree	76°		77°		78°		79°		Minutes
		Ext.	Tan.	Ext.	Tan.	Ext.	Tan.	Ext.	Tan.	
0	.0000	1541.5	4476.7	1591.7	4557.8	1643.1	4640.0	1696.0	4723.4	0
1	.0167	1542.4	4478.1	1592.6	4559.2	1644.0	4641.4	1696.9	4724.8	1
2	.0333	1543.2	4479.4	1593.4	4560.5	1644.8	4642.8	1697.7	4726.2	2
3	.0500	1544.1	4480.8	1594.3	4561.9	1645.7	4644.2	1698.6	4727.6	3
4	.0667	1544.9	4482.1	1595.1	4563.3	1646.6	4645.6	1699.5	4729.0	4
5	.0833	1545.7	4483.5	1596.0	4564.7	1647.5	4647.0	1700.4	4730.4	5
6	.1000	1546.5	4484.8	1596.8	4566.0	1648.3	4648.3	1701.3	4731.8	6
7	.1167	1547.4	4486.2	1597.7	4567.4	1649.2	4649.7	1702.2	4733.3	7
8	.1333	1548.2	4487.5	1598.5	4568.7	1650.1	4651.1	1703.1	4734.7	8
9	.1500	1549.1	4488.9	1599.4	4570.1	1651.0	4652.5	1704.0	4736.1	9
10	.1667	1549.9	4490.2	1600.2	4571.5	1651.8	4653.9	1704.9	4737.5	10
11	.1833	1550.7	4491.6	1601.1	4572.9	1652.7	4655.3	1705.8	4738.9	11
12	.2000	1551.5	4492.9	1601.9	4574.2	1653.6	4656.7	1706.6	4740.3	12
13	.2167	1552.4	4494.3	1602.8	4575.6	1654.5	4658.1	1707.5	4741.7	13
14	.2333	1553.2	4495.6	1603.6	4576.9	1655.3	4659.4	1708.4	4743.1	14
15	.2500	1554.1	4497.0	1604.5	4578.3	1656.2	4660.8	1709.3	4744.5	15
16	.2667	1554.9	4498.3	1605.3	4579.7	1657.1	4662.2	1710.2	4745.9	16
17	.2833	1555.7	4499.7	1606.2	4581.1	1658.0	4663.6	1711.1	4747.3	17
18	.3000	1556.5	4501.0	1607.0	4582.4	1658.8	4665.0	1712.0	4748.7	18
19	.3167	1557.4	4502.4	1607.9	4583.8	1659.7	4666.4	1712.9	4750.1	19
20	.3333	1558.2	4503.7	1608.7	4585.1	1660.6	4667.7	1713.8	4751.5	20
21	.3500	1559.1	4505.0	1609.6	4586.5	1661.5	4669.1	1714.7	4752.9	21
22	.3667	1559.9	4506.3	1610.4	4587.9	1662.3	4670.5	1715.6	4754.3	22
23	.3833	1560.7	4507.7	1611.3	4589.3	1663.2	4671.9	1716.5	4755.7	23
24	.4000	1561.5	4509.0	1612.1	4590.6	1664.1	4673.3	1717.4	4757.1	24
25	.4167	1562.4	4510.4	1613.0	4592.0	1665.0	4674.7	1718.3	4758.6	25
26	.4333	1563.2	4511.7	1613.8	4593.3	1665.8	4676.0	1719.2	4760.0	26
27	.4500	1564.1	4513.1	1614.7	4594.7	1666.7	4677.4	1720.1	4761.4	27
28	.4667	1564.9	4514.4	1615.5	4596.0	1667.6	4678.8	1721.0	4762.8	28
29	.4833	1565.7	4515.8	1616.4	4597.4	1668.5	4680.2	1721.9	4764.2	29
30	.5000	1566.5	4517.1	1617.3	4598.8	1669.3	4681.6	1722.8	4765.6	30
31	.5167	1567.4	4518.5	1618.2	4600.2	1670.2	4683.0	1723.7	4767.0	31
32	.5333	1568.2	4519.8	1619.0	4601.5	1671.1	4684.4	1724.6	4768.4	32
33	.5500	1569.1	4521.1	1619.9	4602.9	1672.0	4685.8	1725.5	4769.8	33
34	.5667	1569.9	4522.5	1620.7	4604.3	1672.8	4687.2	1726.4	4771.2	34
35	.5833	1570.7	4523.9	1621.6	4605.7	1673.7	4688.6	1727.3	4772.7	35
36	.6000	1571.5	4525.3	1622.4	4607.0	1674.6	4689.9	1728.2	4774.1	36
37	.6167	1572.4	4526.7	1623.3	4608.4	1675.5	4691.3	1729.1	4775.5	37
38	.6333	1573.2	4528.0	1624.1	4609.8	1676.3	4692.7	1730.0	4776.9	38
39	.6500	1574.0	4529.4	1625.0	4611.2	1677.3	4694.1	1731.0	4778.3	39
40	.6667	1574.8	4530.7	1625.9	4612.5	1678.2	4695.5	1731.9	4779.7	40
41	.6833	1575.6	4532.1	1626.8	4613.9	1679.1	4696.9	1732.8	4781.1	41
42	.7000	1576.4	4533.4	1627.6	4615.3	1679.9	4698.3	1733.7	4782.6	42
43	.7167	1577.3	4534.8	1628.5	4616.7	1680.8	4699.7	1734.6	4784.0	43
44	.7333	1578.1	4536.1	1629.3	4618.0	1681.7	4701.1	1735.5	4785.4	44
45	.7500	1579.0	4537.5	1630.2	4619.4	1682.6	4702.5	1736.4	4786.8	45
46	.7667	1579.8	4538.8	1631.0	4620.8	1683.5	4703.9	1737.3	4788.2	46
47	.7833	1580.7	4540.2	1631.9	4622.2	1684.4	4705.3	1738.2	4789.6	47
48	.8000	1581.5	4541.5	1632.7	4623.5	1685.3	4706.7	1739.1	4791.0	48
49	.8167	1582.4	4542.9	1633.6	4624.9	1686.2	4708.1	1740.0	4792.5	49
50	.8333	1583.2	4544.2	1634.5	4626.3	1687.1	4709.5	1740.9	4793.9	50
51	.8500	1584.1	4545.6	1635.4	4627.7	1688.0	4710.9	1741.8	4795.3	51
52	.8667	1584.9	4547.0	1636.2	4629.0	1688.8	4712.2	1742.7	4796.7	52
53	.8833	1585.8	4548.4	1637.1	4630.4	1689.7	4713.6	1743.6	4798.1	53
54	.9000	1586.6	4549.7	1637.9	4631.8	1690.6	4715.0	1744.5	4799.5	54
55	.9167	1587.5	4551.1	1638.8	4633.2	1691.5	4716.4	1745.4	4801.0	55
56	.9333	1588.3	4552.4	1639.6	4634.5	1692.4	4717.8	1746.3	4802.4	56
57	.9500	1589.2	4553.8	1640.5	4635.9	1693.3	4719.2	1747.2	4803.8	57
58	.9667	1590.0	4555.1	1641.3	4637.3	1694.2	4720.6	1748.1	4805.2	58
59	.9833	1590.9	4556.5	1642.2	4638.7	1695.1	4722.0	1749.1	4806.6	59

Use 100′ Chords up to 8° Curves
Use 50′ Chords up to 16° Curves
Use 25′ Chords up to 32° Curves
Use 10′ Chords above 32° Curves

Minutes	Dec. of Degree	80°		81°		82°		83°		Minutes
		Ext.	Tan.	Ext.	Tan.	Ext.	Tan.	Ext.	Tan.	
0	.0000	1750.0	4808.0	1805.5	4893.9	1862.3	4981.0	1920.6	5069.4	0
1	.0167	1750.9	4809.5	1806.4	4895.4	1863.3	4982.5	1921.6	5070.9	1
2	.0333	1751.8	4810.9	1807.3	4896.8	1864.2	4983.9	1922.6	5072.4	2
3	.0500	1752.8	4812.3	1808.3	4898.3	1865.2	4985.4	1923.6	5073.9	3
4	.0667	1753.7	4813.7	1809.2	4899.7	1866.1	4986.8	1924.6	5075.4	4
5	.0833	1754.6	4815.2	1810.2	4901.2	1867.1	4988.3	1925.6	5076.9	5
6	.1000	1755.5	4816.6	1811.1	4902.6	1868.1	4989.8	1926.5	5078.4	6
7	.1167	1756.5	4818.0	1812.1	4904.0	1869.1	4991.3	1927.5	5079.9	7
8	.1333	1757.4	4819.4	1813.0	4905.4	1870.0	4992.7	1928.5	5081.4	8
9	.1500	1758.3	4820.9	1814.0	4906.9	1871.0	4994.2	1929.5	5082.9	9
10	.1667	1759.2	4822.3	1814.9	4908.3	1871.9	4995.7	1930.5	5084.4	10
11	.1833	1760.1	4823.7	1815.9	4909.8	1872.9	4997.2	1931.5	5085.9	11
12	.2000	1761.0	4825.1	1816.8	4911.2	1873.9	4998.6	1932.4	5087.3	12
13	.2167	1762.0	4826.6	1817.7	4912.7	1874.9	5000.1	1933.4	5088.8	13
14	.2333	1762.9	4828.0	1818.6	4914.1	1875.8	5001.5	1934.4	5090.3	14
15	.2500	1763.8	4829.4	1819.6	4915.5	1876.8	5003.0	1935.4	5091.8	15
16	.2667	1764.7	4830.8	1820.5	4917.0	1877.7	5004.5	1936.4	5093.3	16
17	.2833	1765.7	4832.3	1821.5	4918.5	1878.7	5006.0	1937.4	5094.8	17
18	.3000	1766.6	4833.7	1822.4	4919.9	1879.7	5007.4	1938.4	5096.3	18
19	.3167	1767.5	4835.1	1823.3	4921.4	1880.7	5008.9	1939.4	5097.8	19
20	.3333	1768.4	4836.5	1824.2	4922.8	1881.6	5010.3	1940.4	5099.3	20
21	.3500	1769.3	4838.0	1825.2	4924.3	1882.6	5011.8	1941.4	5100.8	21
22	.3667	1770.2	4839.4	1826.1	4925.7	1883.5	5013.3	1942.4	5102.3	22
23	.3833	1771.2	4840.8	1827.1	4927.2	1884.5	5014.8	1943.4	5103.8	23
24	.4000	1772.1	4842.2	1828.0	4928.6	1885.5	5016.2	1944.4	5105.2	24
25	.4167	1773.0	4843.7	1829.0	4930.1	1886.5	5017.7	1945.4	5106.7	25
26	.4333	1773.9	4845.1	1829.9	4931.5	1887.4	5019.2	1946.4	5108.2	26
27	.4500	1774.9	4846.5	1830.9	4933.0	1888.4	5020.7	1947.4	5109.7	27
28	.4667	1775.8	4847.9	1831.8	4934.4	1889.3	5022.1	1948.4	5111.2	28
29	.4833	1776.7	4849.4	1832.8	4935.8	1890.3	5023.6	1949.4	5112.7	29
30	.5000	1777.6	4850.8	1833.7	4937.2	1891.3	5025.0	1950.4	5114.2	30
31	.5167	1778.5	4852.3	1834.7	4938.7	1892.3	5026.5	1951.4	5115.7	31
32	.5333	1779.4	4853.7	1835.6	4940.2	1893.2	5028.0	1952.4	5117.2	32
33	.5500	1780.4	4855.1	1836.6	4941.7	1894.2	5029.5	1953.4	5118.7	33
34	.5667	1781.3	4856.5	1837.5	4943.1	1895.1	5031.0	1954.4	5120.2	34
35	.5833	1782.2	4858.0	1838.5	4944.6	1896.1	5032.5	1955.4	5121.7	35
36	.6000	1783.1	4859.4	1839.4	4946.0	1897.1	5033.9	1956.4	5123.2	36
37	.6167	1784.1	4860.9	1840.4	4947.5	1898.1	5035.4	1957.4	5124.7	37
38	.6333	1785.0	4862.3	1841.3	4948.9	1899.0	5036.9	1958.4	5126.2	38
39	.6500	1785.9	4863.7	1842.3	4950.4	1900.0	5038.4	1959.4	5127.7	39
40	.6667	1786.8	4865.1	1843.2	4951.8	1901.0	5039.8	1960.4	5129.2	40
41	.6833	1787.7	4866.6	1844.2	4953.3	1902.0	5041.3	1961.4	5130.7	41
42	.7000	1788.6	4868.0	1845.1	4954.7	1902.9	5042.8	1962.4	5132.2	42
43	.7167	1789.6	4869.5	1846.1	4956.2	1903.9	5044.3	1963.4	5133.7	43
44	.7333	1790.5	4870.9	1847.0	4957.6	1904.9	5045.8	1964.4	5135.2	44
45	.7500	1791.5	4872.4	1848.0	4959.1	1905.9	5047.3	1965.4	5136.7	45
46	.7667	1792.4	4873.8	1848.9	4960.6	1906.9	5048.7	1966.4	5138.2	46
47	.7833	1793.4	4875.2	1849.9	4962.1	1907.9	5050.2	1967.4	5139.7	47
48	.8000	1794.3	4876.6	1850.8	4963.5	1908.8	5051.7	1968.4	5141.2	48
49	.8167	1795.3	4878.1	1851.8	4965.0	1909.8	5053.2	1969.4	5142.8	49
50	.8333	1796.2	4879.5	1852.7	4966.4	1910.8	5054.6	1970.4	5144.3	50
51	.8500	1797.1	4880.9	1853.7	4967.9	1911.8	5056.1	1971.4	5145.8	51
52	.8667	1798.0	4882.4	1854.6	4969.3	1912.8	5057.6	1972.4	5147.3	52
53	.8833	1799.0	4883.9	1855.6	4970.8	1913.8	5059.1	1973.4	5148.8	53
54	.9000	1799.9	4885.3	1856.5	4972.2	1914.7	5060.6	1974.4	5150.3	54
55	.9167	1800.9	4886.7	1857.5	4973.7	1915.7	5062.1	1975.4	5151.8	55
56	.9333	1801.8	4888.1	1858.4	4975.1	1916.7	5063.5	1976.4	5153.3	56
57	.9500	1802.8	4889.6	1859.4	4976.6	1917.7	5065.0	1977.4	5154.8	57
58	.9667	1803.7	4891.0	1860.3	4978.0	1918.7	5066.5	1978.4	5156.3	58
59	.9833	1804.6	4892.5	1861.3	4979.5	1919.7	5068.0	1979.4	5157.8	59

Use 100′ Chords up to 8° Curves
Use 50′ Chords up to 16° Curves
Use 25′ Chords up to 32° Curves
Use 10′ Chords above 32° Curves

Minutes	Dec. of Degree	84° Ext.	84° Tan.	85° Ext.	85° Tan.	86° Ext.	86° Tan.	87° Ext.	87° Tan.	Minutes
0	.0000	1980.5	5159.3	2041.8	5250.6	2104.8	5343.3	2169.5	5437.5	0
1	.0167	1981.5	5160.8	2042.9	5252.1	2105.9	5344.9	2170.6	5439.1	1
2	.0333	1982.5	5162.3	2043.9	5253.6	2106.9	5346.4	2171.6	5440.7	2
3	.0500	1983.5	5163.8	2045.0	5255.2	2108.0	5348.0	2172.7	5442.3	3
4	.0667	1984.5	5165.3	2046.0	5256.7	2109.1	5349.5	2173.8	5443.9	4
5	.0833	1985.6	5166.9	2047.0	5258.3	2110.1	5351.1	2174.9	5445.5	5
6	.1000	1986.6	5168.4	2048.0	5259.8	2111.2	5352.7	2176.0	5447.1	6
7	.1167	1987.6	5169.9	2049.1	5261.4	2112.3	5354.3	2177.1	5448.7	7
8	.1333	1988.6	5171.4	2050.1	5262.9	2113.4	5355.8	2178.2	5450.3	8
9	.1500	1989.6	5172.9	2051.2	5264.5	2114.5	5357.4	2179.3	5451.9	9
10	.1667	1990.6	5174.4	2052.2	5266.0	2115.5	5358.9	2180.4	5453.4	10
11	.1833	1991.7	5175.9	2053.2	5267.5	2116.6	5360.5	2181.5	5455.0	11
12	.2000	1992.7	5177.5	2054.2	5269.0	2117.6	5362.0	2182.5	5456.6	12
13	.2167	1993.7	5179.0	2055.3	5270.6	2118.7	5363.6	2183.6	5458.2	13
14	.2333	1994.7	5180.5	2056.3	5272.1	2119.8	5365.2	2184.7	5459.8	14
15	.2500	1995.7	5182.0	2057.4	5273.7	2120.9	5366.8	2185.8	5461.4	15
16	.2667	1996.7	5183.5	2058.4	5275.2	2121.9	5368.3	2186.9	5463.0	16
17	.2833	1997.8	5185.0	2059.5	5276.8	2123.0	5369.9	2188.0	5464.6	17
18	.3000	1998.8	5186.6	2060.5	5278.3	2124.1	5371.4	2189.1	5466.2	18
19	.3167	1999.8	5188.0	2061.6	5279.9	2125.2	5373.0	2190.2	5467.8	19
20	.3333	2000.8	5189.6	2062.6	5281.4	2126.2	5374.6	2191.3	5469.4	20
21	.3500	2001.8	5191.0	2063.7	5282.9	2127.3	5376.2	2192.4	5471.0	21
22	.3667	2002.8	5192.6	2064.7	5284.4	2128.3	5377.7	2193.5	5472.5	22
23	.3833	2003.9	5194.0	2065.8	5286.0	2129.4	5379.3	2194.6	5474.1	23
24	.4000	2004.9	5195.6	2066.8	5287.5	2130.5	5380.8	2195.7	5475.7	24
25	.4167	2005.9	5197.2	2067.9	5289.1	2131.6	5382.4	2196.8	5477.3	25
26	.4333	2006.9	5198.7	2068.9	5290.6	2132.6	5383.9	2197.9	5478.9	26
27	.4500	2007.9	5200.2	2070.0	5292.2	2133.7	5385.5	2199.0	5480.5	27
28	.4667	2008.9	5201.7	2071.0	5293.7	2134.8	5387.1	2200.1	5482.1	28
29	.4833	2010.0	5203.2	2072.1	5295.2	2135.9	5388.7	2201.2	5483.7	29
30	.5000	2011.0	5204.7	2073.1	5296.7	2136.9	5390.2	2202.3	5485.3	30
31	.5167	2012.0	5206.3	2074.2	5298.3	2138.0	5391.8	2203.4	5486.9	31
32	.5333	2013.0	5207.8	2075.2	5299.8	2139.0	5393.4	2204.5	5488.5	32
33	.5500	2014.0	5209.3	2076.3	5301.4	2140.1	5395.0	2205.6	5490.1	33
34	.5667	2015.0	5210.8	2077.3	5302.9	2141.2	5396.5	2206.8	5491.7	34
35	.5833	2016.0	5212.4	2078.4	5304.5	2142.3	5398.1	2207.9	5493.3	35
36	.6000	2017.0	5213.9	2079.4	5306.1	2143.3	5399.7	2209.0	5494.9	36
37	.6167	2018.0	5215.4	2080.5	5307.7	2144.4	5401.3	2210.1	5496.5	37
38	.6333	2019.1	5216.9	2081.5	5309.2	2145.5	5402.8	2211.2	5498.1	38
39	.6500	2020.1	5218.4	2082.6	5310.8	2146.6	5404.4	2212.3	5499.7	39
40	.6667	2021.2	5220.0	2083.7	5312.3	2147.7	5406.0	2213.4	5501.3	40
41	.6833	2022.2	5221.6	2084.8	5313.9	2148.8	5407.6	2214.5	5502.9	41
42	.7000	2023.2	5223.1	2085.8	5315.4	2149.8	5409.1	2215.6	5504.5	42
43	.7167	2024.3	5224.6	2086.9	5317.0	2150.9	5410.7	2216.7	5506.1	43
44	.7333	2025.3	5226.1	2087.9	5318.5	2152.0	5412.3	2217.8	5507.7	44
45	.7500	2026.4	5227.7	2089.0	5320.1	2153.1	5413.9	2218.9	5509.3	45
46	.7667	2027.4	5229.2	2090.0	5321.6	2154.2	5415.4	2220.0	5510.9	46
47	.7833	2028.4	5230.7	2091.1	5323.2	2155.3	5417.0	2221.2	5512.5	47
48	.8000	2029.4	5232.2	2092.1	5324.7	2156.4	5418.6	2222.3	5514.1	48
49	.8167	2030.5	5233.8	2093.2	5326.3	2157.5	5420.2	2223.4	5515.7	49
50	.8333	2031.5	5235.3	2094.2	5327.8	2158.6	5421.8	2224.5	5517.3	50
51	.8500	2032.6	5236.8	2095.3	5329.4	2159.7	5423.4	2225.6	5518.9	51
52	.8667	2033.6	5238.3	2096.3	5330.9	2160.7	5424.9	2226.7	5520.5	52
53	.8833	2034.6	5239.9	2097.4	5332.5	2161.8	5426.5	2227.9	5522.1	53
54	.9000	2035.6	5241.4	2098.4	5334.0	2162.9	5428.1	2228.9	5523.7	54
55	.9167	2036.7	5243.0	2099.5	5335.6	2164.0	5429.7	2230.0	5525.3	55
56	.9333	2037.7	5244.5	2100.6	5337.1	2165.1	5431.2	2231.1	5526.9	56
57	.9500	2038.7	5246.0	2101.7	5338.7	2166.2	5432.8	2232.2	5528.5	57
58	.9667	2039.8	5247.5	2102.7	5340.2	2167.3	5434.4	2233.3	5530.1	58
59	.9833	2040.8	5249.1	2103.8	5341.8	2168.4	5436.0	2234.5	5531.7	59

Use 100′ Chords up to 8° Curves
Use 50′ Chords up to 16° Curves
Use 25′ Chords up to 32° Curves
Use 10′ Chords above 32° Curves

Minutes	Dec. of Degree	88° Ext.	88° Tan.	89° Ext.	89° Tan.	90° Ext.	90° Tan.	91° Ext.	91° Tan.	Minutes
0	.0000	2235.6	5533.3	2303.6	5630.8	2373.4	5730.0	2445.1	5830.9	0
1	.0167	2236.7	5535.0	2304.7	5632.5	2374.6	5731.7	2446.3	5832.6	1
2	.0333	2237.8	5536.6	2305.6	5634.1	2375.8	5733.3	2447.5	5834.3	2
3	.0500	2238.9	5538.2	2307.2	5635.8	2377.0	5735.0	2448.8	5836.0	3
4	.0667	2240.1	5539.8	2308.1	5637.4	2378.2	5736.7	2450.0	5837.7	4
5	.0833	2241.2	5541.5	2309.4	5639.1	2379.4	5738.4	2451.2	5839.4	5
6	.1000	2242.3	5543.1	2310.5	5640.7	2380.5	5740.0	2452.4	5841.1	6
7	.1167	2243.5	5544.7	2311.6	5642.4	2381.7	5741.7	2453.6	5842.8	7
8	.1333	2244.6	5546.3	2312.8	5644.0	2382.9	5743.4	2454.8	5844.5	8
9	.1500	2245.7	5547.9	2314.0	5645.7	2384.1	5745.1	2456.0	5846.2	9
10	.1667	2246.8	5549.5	2315.1	5647.3	2385.3	5746.7	2457.2	5847.9	10
11	.1833	2248.0	5551.2	2316.3	5649.0	2386.4	5748.4	2458.5	5849.6	11
12	.2000	2249.1	5552.8	2317.4	5650.6	2387.6	5750.0	2459.7	5851.3	12
13	.2167	2250.2	5554.4	2318.6	5652.3	2388.8	5751.7	2460.9	5853.0	13
14	.2333	2251.3	5556.0	2319.7	5653.9	2390.0	5753.4	2462.1	5854.7	14
15	.2500	2252.5	5557.6	2320.9	5655.5	2391.2	5755.1	2463.3	5856.4	15
16	.2667	2253.6	5559.2	2322.0	5657.1	2392.4	5756.7	2464.5	5858.1	16
17	.2833	2254.7	5560.9	2323.2	5658.8	2393.5	5758.4	2465.8	5859.8	17
18	.3000	2255.8	5562.5	2324.3	5660.4	2394.7	5760.1	2467.0	5861.5	18
19	.3167	2257.0	5564.1	2325.6	5662.1	2395.9	5761.8	2468.2	5863.2	19
20	.3333	2258.1	5565.7	2326.7	5663.7	2397.1	5763.4	2469.4	5864.9	20
21	.3500	2259.3	5567.3	2327.9	5665.4	2398.3	5765.1	2470.6	5866.6	21
22	.3667	2260.4	5568.9	2329.0	5667.0	2399.5	5766.8	2471.9	5868.3	22
23	.3833	2261.5	5570.6	2330.1	5668.7	2400.7	5768.5	2473.1	5870.1	23
24	.4000	2262.7	5572.2	2331.3	5670.3	2401.9	5770.1	2474.3	5871.8	24
25	.4167	2263.8	5573.8	2332.5	5672.0	2403.1	5771.8	2475.5	5873.5	25
26	.4333	2264.9	5575.4	2333.7	5673.6	2404.3	5773.5	2476.7	5875.2	26
27	.4500	2266.0	5577.0	2334.8	5675.3	2405.5	5775.2	2478.0	5876.9	27
28	.4667	2267.2	5578.6	2336.0	5676.9	2406.6	5776.9	2479.2	5878.6	28
29	.4833	2268.4	5580.3	2337.1	5678.6	2407.8	5778.6	2480.4	5880.3	29
30	.5000	2269.5	5581.9	2338.3	5680.2	2409.0	5780.2	2481.6	5882.0	30
31	.5167	2270.6	5583.5	2339.5	5681.9	2410.2	5781.9	2482.9	5883.7	31
32	.5333	2271.7	5585.1	2340.7	5683.5	2411.4	5783.6	2484.1	5885.4	32
33	.5500	2272.8	5586.8	2341.9	5685.2	2412.6	5785.3	2485.3	5887.2	33
34	.5667	2273.9	5588.4	2343.0	5686.8	2413.8	5787.0	2486.5	5888.9	34
35	.5833	2275.1	5590.1	2344.1	5688.5	2415.0	5788.7	2487.8	5890.6	35
36	.6000	2276.2	5591.7	2345.3	5690.2	2416.2	5790.3	2489.0	5892.3	36
37	.6167	2277.3	5593.3	2346.5	5691.9	2417.4	5792.0	2490.3	5894.0	37
38	.6333	2278.5	5594.9	2347.7	5693.5	2418.6	5793.7	2491.5	5895.7	38
39	.6500	2279.7	5596.6	2348.9	5695.2	2419.8	5795.4	2492.7	5897.5	39
40	.6667	2280.8	5598.2	2350.0	5696.8	2421.0	5797.1	2493.9	5899.2	40
41	.6833	2281.9	5599.8	2351.2	5698.5	2422.2	5798.8	2495.2	5900.9	41
42	.7000	2283.0	5601.4	2352.3	5700.1	2423.4	5800.4	2496.4	5902.6	42
43	.7167	2284.1	5603.1	2353.5	5701.8	2424.6	5802.1	2497.7	5904.3	43
44	.7333	2285.3	5604.7	2354.7	5703.4	2425.8	5803.8	2498.9	5906.0	44
45	.7500	2286.5	5606.4	2355.8	5705.1	2427.0	5805.5	2500.1	5907.7	45
46	.7667	2287.6	5608.0	2357.0	5706.8	2428.2	5807.2	2501.3	5909.4	46
47	.7833	2288.7	5609.6	2358.1	5708.5	2429.4	5808.9	2502.6	5911.2	47
48	.8000	2289.9	5611.2	2359.3	5710.1	2430.6	5810.6	2503.8	5912.9	48
49	.8167	2291.1	5612.9	2360.5	5711.8	2431.8	5812.3	2505.1	5914.6	49
50	.8333	2292.2	5614.5	2361.7	5713.4	2433.0	5814.0	2506.3	5916.3	50
51	.8500	2293.3	5616.2	2362.9	5715.1	2434.2	5815.7	2507.5	5918.1	51
52	.8667	2294.4	5617.8	2364.0	5716.7	2435.4	5817.3	2508.7	5919.8	52
53	.8833	2295.6	5619.4	2365.1	5718.4	2436.6	5819.0	2510.0	5921.5	53
54	.9000	2296.7	5621.0	2366.3	5720.0	2437.9	5820.7	2511.2	5923.2	54
55	.9167	2297.9	5622.7	2367.5	5721.7	2439.1	5822.4	2512.5	5925.0	55
56	.9333	2299.0	5624.3	2368.7	5723.4	2440.3	5824.1	2513.7	5926.7	56
57	.9500	2300.2	5625.9	2369.9	5725.1	2441.5	5825.8	2515.0	5928.4	57
58	.9667	2301.3	5627.5	2371.0	5726.7	2442.7	5827.5	2516.2	5930.1	58
59	.9833	2302.4	5629.2	2372.2	5728.4	2443.9	5829.2	2517.5	5931.9	59

Use 100′ Chords up to 8° Curves
Use 50′ Chords up to 16° Curves
Use 25′ Chords up to 32° Curves
Use 10′ Chords above 32° Curves

Minutes	Dec. of Degree	92°		93°		94°		95°		Minutes
		Ext.	Tan.	Ext.	Tan.	Ext.	Tan.	Ext.	Tan.	
0	.0000	2518.7	5933.6	2594.2	6038.2	2671.8	6144.7	2751.5	6253.2	0
1	.0167	2520.0	5935.3	2595.5	6040.0	2673.1	6146.5	2752.9	6255.1	1
2	.0333	2521.2	5937.0	2596.8	6041.7	2674.4	6148.3	2754.2	6256.9	2
3	.0500	2522.4	5938.8	2598.1	6043.5	2675.7	6150.1	2755.6	6258.7	3
4	.0667	2523.6	5940.5	2599.3	6045.2	2677.0	6151.9	2756.9	6260.5	4
5	.0833	2524.9	5942.3	2600.6	6047.0	2678.4	6153.7	2758.3	6262.4	5
6	.1000	2526.1	5944.0	2601.9	6048.7	2679.7	6155.4	2759.6	6264.2	6
7	.1167	2527.4	5945.7	2603.2	6050.5	2681.0	6157.2	2761.0	6266.0	7
8	.1333	2528.6	5947.4	2604.4	6052.2	2682.3	6159.0	2762.3	6267.8	8
9	.1500	2529.9	5949.2	2605.7	6054.0	2683.6	6160.8	2763.7	6269.7	9
10	.1667	2531.1	5950.9	2607.0	6055.8	2684.9	6162.6	2765.0	6271.5	10
11	.1833	2532.4	5952.7	2608.3	6057.5	2686.3	6164.4	2766.4	6273.4	11
12	.2000	2533.6	5954.4	2609.6	6059.3	2687.6	6166.2	2767.7	6275.2	12
13	.2167	2534.9	5956.1	2610.9	6061.1	2688.9	6168.0	2769.1	6277.0	13
14	.2333	2536.1	5957.8	2612.1	6062.8	2690.2	6169.8	2770.4	6278.8	14
15	.2500	2537.4	5959.6	2613.4	6064.6	2691.5	6171.6	2771.8	6280.7	15
16	.2667	2538.6	5961.3	2614.7	6066.4	2692.8	6173.4	2773.1	6282.5	16
17	.2833	2539.9	5963.1	2616.0	6068.2	2694.2	6175.2	2774.5	6284.4	17
18	.3000	2541.1	5964.8	2617.3	6069.9	2695.6	6177.0	2775.8	6286.2	18
19	.3167	2542.4	5966.5	2618.6	6071.7	2696.9	6178.8	2777.2	6288.0	19
20	.3333	2543.6	5968.2	2619.8	6073.4	2698.1	6180.6	2778.5	6289.8	20
21	.3500	2544.9	5970.0	2621.1	6075.2	2699.5	6182.4	2779.9	6291.7	21
22	.3667	2546.1	5971.7	2622.4	6077.0	2700.8	6184.2	2781.2	6293.5	22
23	.3833	2547.4	5973.5	2623.7	6078.8	2702.1	6186.0	2782.6	6295.4	23
24	.4000	2548.6	5975.2	2625.0	6080.5	2703.4	6187.8	2784.0	6297.2	24
25	.4167	2549.9	5977.0	2626.3	6082.3	2704.8	6189.7	2785.4	6299.1	25
26	.4333	2551.2	5978.7	2627.6	6084.1	2706.1	6191.5	2786.7	6300.9	26
27	.4500	2552.5	5980.5	2628.9	6085.9	2707.4	6193.3	2788.1	6302.7	27
28	.4667	2553.7	5982.2	2630.2	6087.6	2708.7	6195.1	2789.4	6304.6	28
29	.4833	2555.0	5983.9	2631.5	6089.4	2710.1	6196.9	2790.8	6306.4	29
30	.5000	2556.2	5985.6	2632.7	6091.2	2711.4	6198.7	2792.1	6308.2	30
31	.5167	2557.5	5987.4	2634.0	6093.0	2712.7	6200.5	2793.5	6310.1	31
32	.5333	2558.7	5989.1	2635.3	6094.7	2714.0	6202.3	2794.9	6311.9	32
33	.5500	2560.0	5990.9	2636.6	6096.5	2715.4	6204.1	2796.3	6313.8	33
34	.5667	2561.2	5992.6	2637.9	6098.3	2716.7	6205.9	2797.6	6315.6	34
35	.5833	2562.5	5994.4	2639.2	6100.1	2718.0	6207.7	2799.0	6317.5	35
36	.6000	2563.8	5996.1	2640.5	6101.8	2719.3	6209.5	2800.3	6319.3	36
37	.6167	2565.1	5997.9	2641.8	6103.6	2720.7	6211.4	2801.7	6321.2	37
38	.6333	2566.3	5999.6	2643.1	6105.4	2722.0	6213.2	2803.1	6323.0	38
39	.6500	2567.6	6001.4	2644.4	6107.2	2723.4	6215.0	2804.5	6324.9	39
40	.6667	2568.8	6003.1	2645.7	6109.0	2724.7	6216.8	2805.8	6326.7	40
41	.6833	2570.1	6004.9	2647.0	6110.8	2726.0	6218.6	2807.2	6328.6	41
42	.7000	2571.3	6006.6	2648.3	6112.5	2727.3	6220.4	2808.6	6330.4	42
43	.7167	2572.6	6008.4	2649.6	6114.3	2728.7	6222.3	2810.0	6332.3	43
44	.7333	2573.9	6010.1	2650.9	6116.1	2730.0	6224.1	2811.3	6334.1	44
45	.7500	2575.2	6011.9	2652.2	6117.9	2731.4	6225.9	2812.7	6336.0	45
46	.7667	2576.4	6013.6	2653.5	6119.7	2732.7	6227.7	2814.1	6337.8	46
47	.7833	2577.7	6015.4	2654.8	6121.5	2734.1	6229.5	2815.5	6339.7	47
48	.8000	2578.9	6017.1	2656.1	6123.2	2735.4	6231.3	2816.8	6341.5	48
49	.8167	2580.2	6018.9	2657.4	6125.0	2736.7	6233.2	2818.2	6343.4	49
50	.8333	2581.5	6020.6	2658.7	6126.8	2738.0	6235.0	2819.6	6345.2	50
51	.8500	2582.8	6022.4	2660.0	6128.6	2739.4	6236.8	2821.0	6347.1	51
52	.8667	2584.0	6024.1	2661.3	6130.4	2740.7	6238.6	2822.3	6349.0	52
53	.8833	2585.3	6025.9	2662.6	6132.2	2742.1	6240.5	2823.7	6350.9	53
54	.9000	2586.6	6027.6	2663.9	6133.9	2743.4	6242.3	2825.1	6352.7	54
55	.9167	2587.9	6029.4	2665.3	6135.7	2744.8	6244.2	2826.5	6354.6	55
56	.9333	2589.1	6031.1	2666.6	6137.5	2746.1	6246.0	2827.8	6356.4	56
57	.9500	2590.4	6032.9	2667.9	6139.3	2747.5	6247.8	2829.2	6358.3	57
58	.9667	2591.7	6034.6	2669.2	6141.1	2748.8	6249.6	2830.6	6360.1	58
59	.9833	2593.0	6036.4	2670.5	6142.9	2750.2	6251.4	2832.0	6362.0	59

Use 100′ Chords up to 8° Curves Use 25′ Chords up to 32° Curves
Use 50′ Chords up to 16° Curves Use 10′ Chords above 32° Curves

Minutes	Dec. of Degree	96°		97°		98°		99°		Minutes
		Ext.	Tan.	Ext.	Tan.	Ext.	Tan.	Ext.	Tan.	
0	.0000	2833.4	6363.8	2917.5	6476.6	3004.0	6591.6	3092.9	6709.0	0
1	.0167	2834.8	6365.7	2918.9	6478.5	3005.5	6593.6	3094.4	6711.0	1
2	.0333	2836.1	6367.5	2920.3	6480.4	3006.9	6595.5	3095.9	6712.9	2
3	.0500	2837.5	6369.4	2921.8	6482.3	3008.4	6597.5	3097.4	6714.9	3
4	.0667	2838.9	6371.3	2923.2	6484.2	3009.8	6599.4	3098.9	6716.9	4
5	.0833	2840.3	6373.2	2924.6	6486.1	3011.3	6601.3	3100.4	6718.9	5
6	.1000	2841.7	6375.0	2926.0	6488.0	3012.8	6603.2	3101.9	6720.8	6
7	.1167	2843.1	6376.9	2927.5	6489.9	3014.3	6605.2	3103.4	6722.8	7
8	.1333	2844.5	6378.7	2928.9	6491.8	3015.7	6607.1	3104.9	6724.8	8
9	.1500	2845.9	6380.6	2930.3	6493.7	3017.2	6609.1	3106.4	6726.8	9
10	.1667	2847.2	6382.5	2931.7	6495.6	3018.6	6611.0	3107.9	6728.8	10
11	.1833	2848.6	6384.4	2933.2	6497.5	3020.1	6613.0	3109.5	6730.8	11
12	.2000	2850.0	6386.2	2934.6	6499.4	3021.6	6614.9	3111.0	6732.7	12
13	.2167	2851.4	6388.1	2936.1	6501.3	3023.1	6616.9	3112.5	6734.7	13
14	.2333	2852.8	6389.9	2937.5	6503.2	3024.5	6618.8	3114.0	6736.7	14
15	.2500	2854.2	6391.8	2938.9	6505.2	3026.0	6620.8	3115.5	6738.7	15
16	.2667	2855.6	6393.7	2940.3	6507.1	3027.5	6622.7	3117.0	6740.7	16
17	.2833	2857.0	6395.6	2941.8	6509.0	3029.0	6624.7	3118.5	6742.7	17
18	.3000	2858.4	6397.4	2943.2	6510.9	3030.4	6626.6	3120.0	6744.6	18
19	.3167	2859.8	6399.3	2944.7	6512.8	3031.9	6628.6	3121.5	6746.6	19
20	.3333	2861.2	6401.2	2946.1	6514.7	3033.3	6630.5	3123.1	6748.6	20
21	.3500	2862.6	6403.1	2947.5	6516.6	3034.8	6632.5	3124.6	6750.6	21
22	.3667	2864.0	6404.9	2948.9	6518.5	3036.3	6634.4	3126.1	6752.6	22
23	.3833	2865.4	6406.8	2950.4	6520.4	3037.8	6636.4	3127.6	6754.6	23
24	.4000	2866.7	6408.7	2951.8	6522.3	3039.3	6638.3	3129.1	6756.6	24
25	.4167	2868.1	6410.6	2953.3	6524.3	3040.8	6640.3	3130.7	6758.6	25
26	.4333	2869.5	6412.4	2954.7	6526.2	3042.2	6642.2	3132.2	6760.6	26
27	.4500	2870.9	6414.3	2956.2	6528.1	3043.7	6644.2	3133.7	6762.6	27
28	.4667	2872.3	6416.2	2957.6	6530.0	3045.2	6646.1	3135.2	6764.6	28
29	.4833	2873.7	6418.1	2959.0	6531.9	3046.7	6648.1	3136.7	6766.6	29
30	.5000	2875.1	6419.9	2960.4	6533.8	3048.1	6650.0	3138.3	6768.6	30
31	.5167	2876.5	6421.8	2961.9	6535.8	3049.6	6652.0	3139.8	6770.6	31
32	.5333	2877.9	6423.7	2963.3	6537.7	3051.1	6653.9	3141.3	6772.6	32
33	.5500	2879.4	6425.6	2964.8	6539.6	3052.6	6655.9	3142.9	6774.6	33
34	.5667	2880.8	6427.5	2966.2	6541.5	3054.1	6657.8	3144.4	6776.6	34
35	.5833	2882.2	6429.4	2967.7	6543.4	3055.6	6659.8	3145.9	6778.6	35
36	.6000	2883.6	6431.2	2969.1	6545.3	3057.0	6661.7	3147.4	6780.6	36
37	.6167	2885.0	6433.1	2970.6	6547.3	3058.5	6663.7	3149.0	6782.6	37
38	.6333	2886.4	6435.0	2972.0	6549.2	3060.0	6665.7	3150.5	6784.6	38
39	.6500	2887.8	6436.9	2973.5	6551.1	3061.5	6667.7	3152.0	6786.6	39
40	.6667	2889.2	6438.8	2974.9	6553.0	3063.0	6669.6	3153.5	6788.6	40
41	.6833	2890.6	6440.7	2976.4	6555.0	3064.5	6671.6	3155.1	6790.6	41
42	.7000	2892.0	6442.5	2977.8	6556.9	3066.0	6673.5	3156.6	6792.6	42
43	.7167	2893.4	6444.4	2979.3	6558.8	3067.5	6675.5	3158.2	6794.6	43
44	.7333	2894.8	6446.3	2980.7	6560.7	3068.9	6677.4	3159.7	6796.6	44
45	.7500	2896.3	6448.2	2982.2	6562.7	3070.4	6679.4	3161.2	6798.6	45
46	.7667	2897.7	6450.1	2983.6	6564.6	3071.9	6681.4	3162.7	6800.6	46
47	.7833	2899.1	6452.0	2985.1	6566.5	3073.4	6683.4	3164.3	6802.6	47
48	.8000	2900.5	6453.9	2986.5	6568.4	3074.9	6685.3	3165.8	6804.6	48
49	.8167	2901.9	6455.8	2988.0	6570.4	3076.4	6687.3	3167.4	6806.6	49
50	.8333	2903.3	6457.6	2989.4	6572.3	3077.9	6689.2	3168.9	6808.6	50
51	.8500	2904.7	6459.5	2990.9	6574.3	3079.4	6691.2	3170.5	6810.6	51
52	.8667	2906.1	6461.4	2992.3	6576.2	3080.9	6693.2	3172.0	6812.6	52
53	.8833	2907.6	6463.3	2993.8	6578.1	3082.4	6695.2	3173.6	6814.7	53
54	.9000	2909.0	6465.2	2995.2	6580.0	3083.9	6697.1	3175.1	6816.7	54
55	.9167	2910.4	6467.1	2996.7	6582.0	3085.4	6699.1	3176.6	6818.7	55
56	.9333	2911.8	6469.0	2998.1	6583.9	3086.9	6701.1	3178.1	6820.7	56
57	.9500	2913.3	6470.9	2999.6	6585.8	3088.4	6703.2	3179.7	6822.7	57
58	.9667	2914.7	6472.8	3001.1	6587.7	3089.9	6705.2	3181.2	6824.7	58
59	.9833	2916.1	6474.7	3002.6	6589.7	3091.4	6707.1	3182.8	6826.8	59

Use 100′ Chords up to 8° Curves
Use 50′ Chords up to 16° Curves
Use 25′ Chords up to 32° Curves
Use 10′ Chords above 32° Curves

Minutes	Dec. of Degree	100° Ext.	100° Tan.	Minutes
0	.0000	3184.3	6828.8	0
1	.0167	3185.9	6830.8	1
2	.0333	3187.4	6832.8	2
3	.0500	3189.0	6834.8	3
4	.0667	3190.5	6836.8	4
5	.0833	3192.1	6838.9	5
6	.1000	3193.6	6840.9	6
7	.1167	3195.2	6842.9	7
8	.1333	3196.7	6844.9	8
9	.1500	3198.3	6847.0	9
10	.1667	3199.8	6849.0	10
11	.1833	3201.4	6851.0	11
12	.2000	3202.9	6853.0	12
13	.2167	3204.5	6855.1	13
14	.2333	3206.0	6857.1	14
15	.2500	3207.6	6859.1	15
16	.2667	3209.1	6861.1	16
17	.2833	3210.7	6863.2	17
18	.3000	3212.2	6865.2	18
19	.3167	3213.8	6867.2	19
20	.3333	3215.4	6869.2	20
21	.3500	3217.0	6871.3	21
22	.3667	3218.5	6873.3	22
23	.3833	3220.1	6875.4	23
24	.4000	3221.6	6877.4	24
25	.4167	3223.2	6879.4	25
26	.4333	3224.7	6881.4	26
27	.4500	3226.3	6883.5	27
28	.4667	3227.9	6885.5	28
29	.4833	3229.5	6887.6	29
30	.5000	3231.0	6889.6	30
31	.5167	3232.6	6891.7	31
32	.5333	3234.1	6893.7	32
33	.5500	3235.7	6895.7	33
34	.5667	3237.3	6897.8	34
35	.5833	3238.9	6899.8	35
36	.6000	3240.4	6901.8	36
37	.6167	3242.0	6903.9	37
38	.6333	3243.5	6905.9	38
39	.6500	3245.1	6908.0	39
40	.6667	3246.7	6910.0	40
41	.6833	3248.3	6912.1	41
42	.7000	3249.8	6914.1	42
43	.7167	3251.4	6916.2	43
44	.7333	3253.0	6918.2	44
45	.7500	3254.6	6920.3	45
46	.7667	3256.2	6922.3	46
47	.7833	3257.8	6924.4	47
48	.8000	3259.3	6926.4	48
49	.8167	3260.9	6928.5	49
50	.8333	3262.5	6930.5	50
51	.8500	3264.1	6932.6	51
52	.8667	3265.7	6934.6	52
53	.8833	3267.3	6936.7	53
54	.9000	3268.8	6938.7	54
55	.9167	3270.4	6940.8	55
56	.9333	3272.0	6942.8	56
57	.9500	3273.6	6944.9	57
58	.9667	3275.2	6946.9	58
59	.9833	3276.8	6949.0	59

Use 100′ Chords up to 8° Curves
Use 50′ Chords up to 16° Curves
Use 25′ Chords up to 32° Curves
Use 10′ Chords above 32° Curves

Minutes	101°		102°		103°		104°		105°		Minutes
	Ext.	Tan.	Ext.	Tan.	Ext.	Tan.	Ext.	Tan.	Ext.	Tan.	
0	3278.3	6951.0	3375.1	7076.0	3474.6	7203.6	3577.1	7334.1	3682.6	7467.5	0
10	3294.3	6971.7	3391.5	7097.1	3491.5	7225.1	3594.4	7356.1	3700.4	7490.0	10
20	3310.3	6992.4	3407.9	7118.2	3508.4	7246.8	3611.9	7378.2	3718.4	7512.6	20
30	3326.4	7013.2	3424.5	7139.4	3525.5	7268.5	3629.4	7400.4	3736.5	7535.3	30
40	3342.5	7034.0	3441.1	7160.7	3542.6	7290.3	3647.1	7422.7	3754.6	7558.1	40
50	3358.8	7055.0	3457.8	7182.1	3559.8	7312.1	3664.8	7445.0	3772.9	7581.0	50
60	3375.1	7076.0	3474.6	7203.6	3577.1	7334.1	3682.6	7467.5	3791.2	7604.0	60

Minutes	106°		107°		108°		109°		110°		Minutes
	Ext.	Tan.	Ext.	Tan.	Ext.	Tan.	Ext.	Tan.	Ext.	Tan.	
0	3791.2	7604.0	3903.1	7743.7	4018.5	7886.7	4137.4	8033.2	4260.0	8183.3	0
10	3809.6	7627.0	3922.1	7767.3	4038.0	7910.8	4157.5	8057.9	4280.8	8208.7	10
20	3828.1	7650.2	3941.2	7791.0	4057.7	7935.1	4177.8	8082.8	4301.7	8234.2	20
30	3846.7	7673.4	3960.4	7814.7	4077.5	7959.5	4198.2	8107.8	4322.7	8259.8	30
40	3865.4	7696.7	3979.6	7838.6	4097.3	7983.9	4218.7	8132.8	4343.8	8285.5	40
50	3884.2	7720.1	3999.0	7862.6	4117.3	8008.5	4239.3	8158.0	4365.1	8311.3	50
60	3903.1	7743.7	4018.5	7886.7	4137.4	8033.2	4260.0	8183.3	4386.4	8337.2	60

Minutes	111°		112°		113°		114°		115°		Minutes
	Ext.	Tan.	Ext.	Tan.	Ext.	Tan.	Ext.	Tan.	Ext.	Tan.	
0	4386.4	8337.2	4516.9	8495.1	4651.6	8657.1	4790.7	8823.4	4934.4	8994.3	0
10	4407.9	8363.2	4539.1	8521.8	4674.5	8684.5	4814.4	8851.6	4958.9	9023.2	10
20	4429.5	8389.4	4561.3	8548.6	4697.5	8712.0	4838.1	8879.9	4983.4	9052.3	20
30	4451.2	8415.6	4583.7	8575.6	4720.6	8739.7	4862.0	8908.3	5008.1	9081.5	30
40	4473.0	8442.0	4606.2	8602.6	4743.9	8767.5	4885.0	8936.8	5032.9	9110.8	40
50	4494.9	8468.5	4628.9	8629.8	4767.2	8795.4	4910.2	8965.5	5057.9	9140.3	50
60	4516.9	8495.1	4651.6	8657.1	4790.7	8823.4	4934.4	8994.3	5083.0	9169.9	60

Minutes	116°		117°		118°		119°		120°		Minutes
	Ext.	Tan.	Ext.	Tan.	Ext.	Tan.	Ext.	Tan.	Ext.	Tan.	
0	5083.0	9169.9	5236.6	9350.5	5395.4	9536.3	5559.7	9727.6	5730.0	9,924.6	0
10	5108.2	9199.7	5262.6	9381.1	5422.4	9567.8	5587.7	9760.0	5758.9	9,958.1	10
20	5133.6	9229.6	5288.9	9411.9	5449.5	9599.5	5615.8	9792.6	5788.0	9,990.6	20
30	5159.1	9259.6	5315.3	9442.8	5476.8	9631.3	5644.1	9825.4	5817.3	10,025.6	30
40	5184.8	9289.8	5341.8	9473.8	5504.3	9663.2	5672.6	9858.3	5846.8	10,059.7	40
50	5210.6	9320.1	5368.5	9505.0	5532.0	9695.3	5701.2	9891.4	5876.4	10,093.7	50
60	5236.6	9350.5	5395.4	9536.3	5559.7	9727.6	5730.0	9924.6	5906.1	10,127.7	60

$$L = 100 \times \frac{\Delta}{D} = \frac{\text{Central angle}}{\text{Degree of curvature}} \times 100.$$

For the convenience of the field engineer column 1, Table 139, gives the central angle Δ in degrees and minutes (as read by the transit); column 2 gives the same angle expressed in degrees and decimals for figuring curve lengths.

Tangent Length and Externals.—Figure 278 shows a general curve problem. The deflection angle between the tangents at the point of intersection (P. I.) = the central angle of the curve that will fit these tangents; it is referred to as Δ.

The tangent distances equal the distance from the P. C. (beginning of curve) to the P. I. or P. I. to P. T. (end of curve) and are expressed by the formula

$$T = \text{Radius} \times \text{tangent of } \frac{\Delta}{2}. \qquad (4)$$

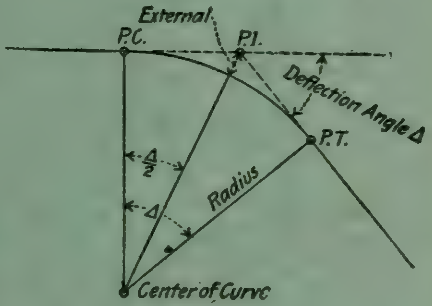


FIG. 278.

Therefore, for a given central angle Δ, the tangent length is directly proportional to the radius. If the tangent lengths of a 1° curve for different Δ's are tabulated, the tangent length for any desired degree of curve equals tangent length for 1° curve for the specified Δ divided by the degree of the desired curve expressed in degrees and decimals of a degree.

Expressed as a formula this reads:

$$\text{Tangent for desired curve} = \frac{\text{Tangent } 1^\circ \text{ curve for specified } \Delta}{D}, \qquad (5)$$

and reversing the formula the desired degree of curve for a specified tangent length can be determined by the formula

$$D = \frac{\text{Tangent } 1^\circ \text{ curve for specified } \Delta}{\text{Specified tangent length desired}}. \qquad (6)$$

The external is the distance from the P. I. to the curve arc on the line between the P. I. and the center of the curve. It is determined by the formula:

$$\text{External} = \frac{\text{Radius}}{\text{Cos } \frac{\Delta}{2}} - \text{Radius} = \text{Radius}\left(\frac{1}{\text{Cos } \frac{\Delta}{2}} - 1\right) \qquad (7)$$

and is directly proportional to the radius in the same manner a the tangent length; therefore, the external of any desired curv for a specified Δ equals the external of a 1° curve for that Δ divide by the degree of curvature.

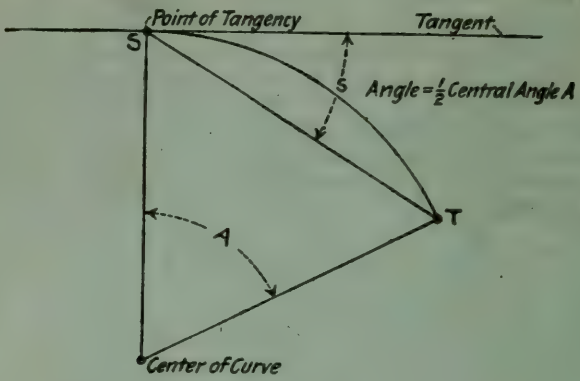


FIG. 279.

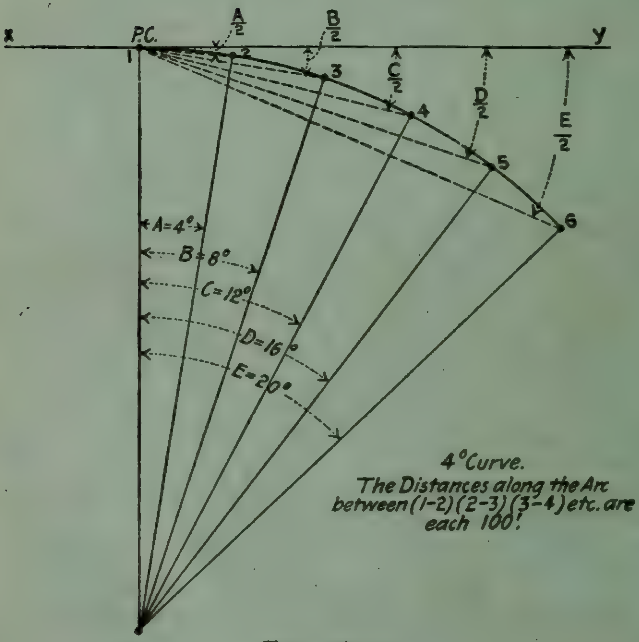


FIG. 280.

Expressed as a formula this reads:

$$\text{External for desired curve} = \frac{\text{External } 1^\circ \text{ curve for specified } \Delta}{D}, \quad (8$$

and reversing, as for tangents, the desired degree of curvature is obtained that gives a specified external distance, by the formula,

$$D = \frac{\text{External } 1^\circ \text{ curve for specified } \Delta}{\text{Specified external distance desired}}. \tag{9}$$

Methods of Running Curves.—Curves are run in the field by tangent offsets, middle ordinates, or deflection angles. Deflection angles is the simplest method and is almost universally used. It is based on the principle that the angle S between the tangent and arc chord, one end of which is at the point of tangency, is equal to one-half the central angle subtended by that chord. Suppose the angle A is 4° and the arc length ST = 100′. This curve would then be a 4° curve. From the previous definitions locate the point T (Fig. 279) by turning the deflection angle S = 2° from the tangent and measuring 100′ of arc in such a position that the end of the arc would be on the line of the chord ST. It is impossible to measure the arc distance conveniently and for all practical purposes a chord length of 100′ will answer for a 4° curve (see discussion, p. 855).

Suppose it is desired to locate the points 2, 3, 4, 5, and 6 on the 4° curve from point 1 or the P.C. of a curve (Fig. 280).

Set the transit at the P.C.; if a deflection $\frac{A}{2}$ = 2° from the tangent xy is turned the line of sight will pass through the point 2; if $\frac{B}{2}$ = 4° is turned the line of sight will pass through point 3; 6°, point 4, etc.; it only remains to measure to these points to locate them definitely. This can be done in two ways, by measuring the distances 1–2, 1–3, 1–4, 1–5, etc., or by measuring 1–2, 2–3, 3–4, 4–5, etc.

In the first case the difference between the length of arc and the chord length becomes so great that, unless a correction is made, the points are not exactly located; that is, the length of arc between points 1, 2, 3, 4, 5, 6, = 500′ while the chord length 1–6 = 497.5′; also, it takes longer to measure the distances 1–2, 1–3, 1–4, 1–5, 1–6, etc., than it would 1–2, 2–3, 3–4, 4–5, etc.

In the second method we can use chords of 100′ from 1–2, 2–3, etc., with no appreciable error, as the distance measured by chords 1, 2, 3, 4, 5, 6, = 499.94′.

Therefore, the method usually adopted is to turn the deflection angle $\frac{A}{2}$ and measure the chord 1–2, which locates the point 2; then turn the deflection angle $\frac{B}{2}$ and measure the chord distance 2–3, locating point 3, etc.

The fact has been mentioned that the use of the chord distance as equal to the arc introduces an error but that this error is of no importance for a 4° curve: As the degree of curvature increases, the difference between an arc length of 100′ and the chord length becomes greater, and it is necessary to determine the limit of

curvature that will allow the use of 100′ chords in locating curve points. On page 832 the statement is made that center-line chaining should be correct to within 0.1′ per 100′ of length, which allows a difference in arc and chord of 0.1. This occurs when the degree of curvature reaches 9° per 100′. The difference can then be reduced by the simple expedient ofusing 50′ chords, which reduces the error for this degree of curvature from 0.10′ per 100′ of length using 100′ chords to 0.02′ using 50′ chords; 50′ chords can be used up to 18° curves and beyond that point 25′ chords.

It is better not to use the full limit of allowable error, and a good working rule is 100′ chords up to 8° curves, 50′ chords up to 16° curves, 25′ chords to 32°, and beyond that 10′ chords.

For any given curve the deflection angle and central angle are directly proportional to the length of the arc, and if the deflection angle for 100′ arc of 10° curve equals 5° the deflection angle for 1 foot of arc of 10° curve equals $\frac{5^\circ}{100} = \frac{300'}{100} = 3'$.

An example of a typical simple curve problem can now be given:

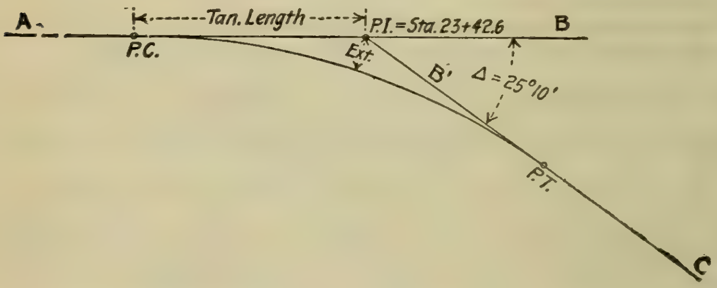


FIG. 281.

To Determine the Degree of Curvature Desired from a Fixed External Distance.—At Sta. 23 + 42.6 there is a deflection angle of 25° 10′ between tangents AB and $B'C$; suppose upon examining the ground it is decided that to fit the old roadbed and give good alignment the curve should be located somewhere between 13.5 and 14.5′ to the right of the transit point at Sta. 23 + 42.6. Proceed as follows: From table 139 pick out the external for a 1° curve for $\Delta = 25°\ 10'$; this equals 141.0′.

The problem is to determine the degree of curvature that will give an external of between 13.5 and 14.5′. Use formula (9).

$$D = \frac{\text{External } 1^\circ \text{ curve for } 25^\circ\ 10'}{13.5'} = \frac{141.0'}{13.5'} = 10.44^\circ \text{ curve.}$$

$$D = \frac{\text{External } 1^\circ \text{ curve for } 25^\circ\ 10'}{14.5'} = \frac{141.0'}{14.5} = 9.72^\circ \text{ curve.}$$

To fit the conditions some curve must be selected between a 10.44 and a 9.72°. A 10° curve would be naturally selected as being the simplest to figure.

To Determine the Required Degree of Curvature for a Fixed Tangent Length.—Take the same problem as above except there must be a tangent length of between 127 and 129′. Use formula (6).

$$D = \frac{\text{Tangent } 1^\circ \text{ curve for } 25^\circ\ 10'}{127'} = \frac{1279.1'}{127'} = 10.07^\circ \text{ curve.}$$

$$D = \frac{\text{Tangent } 1^\circ \text{ curve for } 25^\circ\ 10'}{129'} = \frac{1279.1'}{129'} = 9.91^\circ \text{ curve.}$$

Table 139 gives tangent for 25° 10′ = 1279.1′.

These limiting values would result in the selection of a 10° curve. The degree of the desired curve is usually selected in one of these two ways; ordinarily it is determined by the external distance.

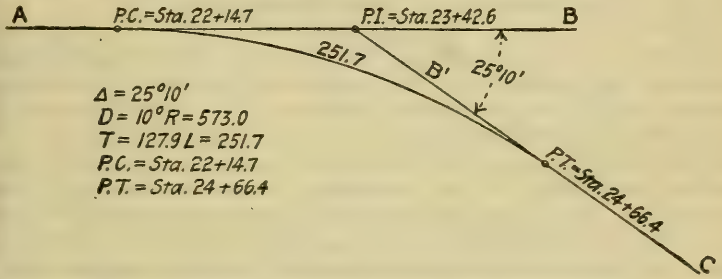


FIG. 282.

Simple Curve Problem. Case 1.—To compute the notes for a 10° curve for a deflection angle of 25° 10′ between tangents at Sta. 23 + 42.6.

Central angle = 25° 10′.

Table 139 gives the tangent 1° curve for 25° 10′ = 1279.1.

$$\text{Tangent } 10^\circ \text{ curve} = \frac{1279.1}{10} = 127.91.$$

The station of the P.C. then equals Sta. 23 + 42.6 P.I. minus 127.9′ = Sta. 22 + 14.7.

$$\text{The length of curve} = \frac{\Delta}{D} = \frac{25.16667^\circ}{10^\circ} \times 100' = 251.7'.$$

The station of the P.T. (tangent point, or end of the curve) as measured around the arc is then Sta. (22 + 14.7 P.C.) + 251.7′ = Sta. 24 + 66.4.

The rule for running curves requires the use of 50′ chords for a 10° curve. The deflections for the even stations and the 50′ stations must, therefore, be figured as follows:

Stations 22 + 50, 23 + 00, 23 + 50, 24 + 00, 24 + 50, and to check the curve Sta. 24 + 66.4.

For a 10° curve, Table 138:

The deflection for 100′ of arc = 5°
The deflection for 50′ of arc = 2° 30′
The deflection for 1′ of arc = 0° 03′

The distance from the P.C., Stas. 22 + 14.7 to 22 + 50, is 35.3′ the deflection per foot = 0° 03′, for 35.3′ = 35.3 × 0° 03′ = 105.9 = 1° 46′.

The distance P.C. to Sta. 23 + 00 equals 85.3′, or 50′ farthe than for Sta. 22 + 50; the deflection per 50′ of arc equals 2° 30′ therefore, the deflection for Sta. 23 + 00 equals the deflections fo Sta. 22 + 50 (1° 46′) plus 2° 30′, the deflection for 50′ of arc or 4 16′; in a like manner the deflection for Sta. 23 + 50 is 6° 46′; fo 24 + 00, 9° 16′; for 24 + 50, 11° 46′; the distance from Sta. 2 + 50 to the P.T., Sta. 24 + 66.4, is 16.4; the deflection for 16.4 equals 16.4 × 0° 03′ = 49.2′; the deflection for Sta. 24 + 66.4 is therefore, (11° 46′ + 49′) = 12° 35′; if the deflection notes hav been properly figured this last deflection to the P.T. should alway be one-half the central angle of the curve; in this case one-half o 25° 10′, which equals 12° 35′, checking the notes.

To Run the Curve.—Set up the transit at the P.I.; sight alon the tangent (*BA*), measure off the distance 127.9 (tangent length along this line and set the P.C. exactly on the line. In a like man ner set the P.T. on the forward tangent (*B′C*) 127.9′ from the P.I Then set up the transit on the P.C. and with the vernier at 0° 0 sight on the P.I., using the lower plate motion. Loosen the uppe motion and deflect 1° 46′; measure along this line 35.3′, whic locates Sta. 22 + 50 on the curve arc; then loosen the upper motio and set the vernier to read 4° 16′; measure 50′ from the just locate Sta. 22 + 50, so that the forward end of the tape is in line with th transit deflection of 4° 16′; this locates Sta. 23 + 00 on th curve arc. In a like manner deflect 6° 46′ and measure forwar 50′ from Stas. 23 + 00 to 23 + 50, etc., until the P.T. is reache If the curve has been correctly run the last deflection of 12° 35′ wi strike the previously located P.T. and the distance from Sta. 2 + 50 to this P.T. will be 16.4′; if the distance checks within 0.2′ i is sufficiently close.

The above problem and method of laying out a curve are th simplest form encountered; it is assumed that the P.I., P.T. an all intermediate points on the curve are visible from the P.C. an that the P.I. is accessible.

In nine cases out of ten this method is applicable to road curve but where the P.I. occurs outside of the road fences it sometime is located in a stream, pond, building, etc., and cannot b occupied. This is known as the problem of the inaccessible P.I More often it is impossible to see the P.T., or some intermediat point on the curve from the P.C., which necessitates intermediat transit points on the curve. The problem of inaccessible P.C.'s o P.T.'s is so rare it will not be illustrated.

Problem of the Inaccessible P.I. Case 2.—The point *H* (P.I. cannot be occupied. Locate any two convenient points *s* and on the tangents *AB* and *B′C* and measure the distance *st* equals say, 110.5′.

Set the transit at *s* and measure the angle between the line *A* produced and *st*, say, 5° 10′; in a similar manner measure the angl at *t* between *st* produced and the forward tangent *tC*, say, 20° 00′ The total deflection then between the tangent *AsB* and *B′tC* or th

central angle of the curve to be run is the sum of these two deflections, angles $5° \, 10' + 20° \, 00' = 25° \, 10'$.

Assuming a 10° curve is desired we must locate the P.C. from the point *s* and the P.T. from the point *t*.

In the preceding simple curve problem the tangent length of a 10° curve with a central angle of 25° 10′ was figured to be 127.9′; it, therefore, remains to compute the distance *sH*, which subtracted from 127.9′ will give the distance from *s* along the tangent *sA* to the P.C. of the curve. In a similar manner compute *tH*, which subtracted from 127.9′ gives the distance along the forward tangent *tC* to the P.T. of the curve.

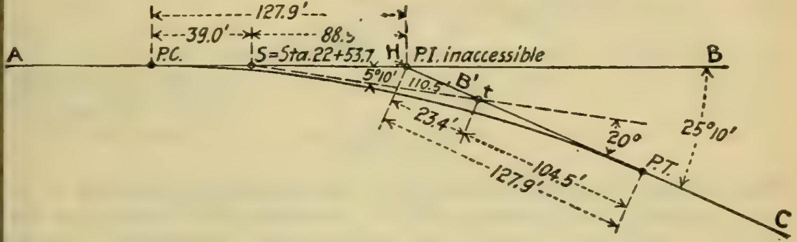


FIG. 283.

Knowing the station of the point *s* as measured along the tangent *AB* the station of the P.C. is determined; then figure the deflections in the usual manner and run the curve.

For the values given the computations are as follows:

To determine *sH* and *Ht*. Use the law of sines (see Trigonometric formulas, p. 1578).

$sH : st :: \sin 20° \, 00' :: \sin 25° \, 10'$

$$sH = \frac{st \sin 20° \, 00'}{\sin 25° \, 10'} = \frac{110.5 \times 0.34202}{0.42525} = 88.87 .$$

$$Ht = \frac{st \sin 5° \, 10'}{\sin 25° \, 10'} = \frac{110.5 \times 0.09005}{0.42525} = 23.4'.$$

Therefore, the distance from *s* to the P.C. is $127.9' - 88.9' = 39.0'$.

The distance from *t* to the P.T. is $127.9 - 23.4 = 104.5$.

Having these distances, the P.C. and P.T. are located. Assume that station of *s* was measured along the tangent *AB* and found to be Sta. 22 + 53.7.

The station of the P.C. then equals 22 + 14.7

The station of the P.I. then equals 23 + 42.6

The station of the P.T. then equals 24 + 66.4, using the length of curve figured in Case 1.

The deflections are figured and the curve run as in Case 1, assuming that all the curve points are visible from the P.C.

Case 3. Where the P.T. or Intermediate Points on the Curve Are Not Visible from the P.C. *a. Where an Intermediate Set-up Is Required.*—Use the same curve as in Case 1.

The deflections for the different curve points were figured as follows:

Deflections.—Instrument at P.C., foresight on P.I.

P.C. Sta.	Deflection
22 + 14.7	0° 00′
22 + 50	1° 46′
23 + 00	4° 16′
23 + 50	6° 46′
24 + 00	9° 16′
24 + 50	11° 46′
24 + 66.4	12° 35′

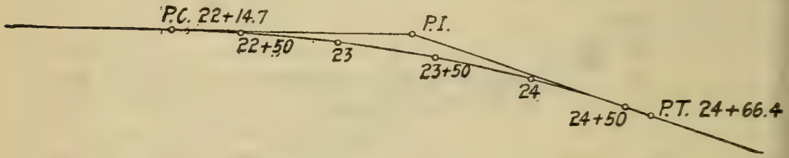


FIG. 284.

Set up the instrument at the P.C. and locate the points 22 + 50 23 + 00, and 23 + 50; suppose 24 + 00 is not visible, set up at Sta. 23 + 50, set the vernier at 0° 00′, and back sight on the P.C.; transit the telescope and finish the curve, using the same deflections as figured for the instrument set up at the P.C.; that is, turn the deflection of 9° 16′ for Sta. 24 + 00, 11° 46′ for 24 + 50, and 12° 35′ for the P.T. In general, it can be said that whenever the P.C. is used as a backsight from the intermediate set-up, set the vernier at 0° 00′ when sighting on the P.C.; transit the telescope and use original notes for the balance of the curve.

b. Where Two or More Intermediate Set-ups Are Required.—For the first set-up, say, at 23 + 50, proceed as above and set Sta. 24 + 00; suppose 24 + 50 is not visible from Sta. 23 + 50; set up at Sta. 24 + 00 and with the vernier reading 6° 46′, back sight on Sta. 23 + 50; transit the telescope, set the vernier to read 11° 46′ for Sta. 24 + 50, and proceed, using the same deflections as originally figured. In general, where the P.C. is not visible from the intermediate set-up, set the vernier to read the deflection figured for the point used as a backsight; transit the telescope and proceed with the curve, using the notes originally figured; that is, if the instrument is set up at Sta. 24 + 00 and 22 + 50 used as a backsight, the vernier is set at 1° 46′, and using the lower motion the wire is set on Sta. 22 + 50; then transiting the telescope the curve is run by setting the vernier at 11° 46′ for Sta. 24 + 50, etc.

If Sta. 23 + 00 is used as a backsight, set the vernier at 4° 16′ when sighting the machine; then transit and proceed as above.

These three cases cover any ordinary road curve problems.

NEW LOCATION SURVEYS

General.—The details of survey work depend entirely on the character of the improvement and range from simple alignment determination on mesa wagon trails to the complete surveys

equired for difficult mountain locations which are to be constructed y contract on unit price bids. The following data are for complete irst-class surveys. The same methods are used for more incomplete surveys, but parts of the procedure can often be omitted if the ork is to be done by force account or convict labor.

Organization and Equipment.—Eight- to ten-men parties are a onvenient and efficient force:

Locating engineer
Transitman
Levelman
3 Chainmen, rodmen, etc.
1 to 3 Axmen.
Cook

If drafting is to be done in the field, add a draftsman and omputer to the party, but this is not advised, as field drafting is arely satisfactory.

Organization—first stage of work:

Locating engineer	Picking out line and general supervision.
Transitman 2 Chainmen Necessary axmen 1 Stakeman	Running base line.
Levelman Rodman	Running bench levels and check profile levels keeping all this work close up to base-line party.

Organization—second stage of work:

Locating engineer 1 Assistant	Drainage areas, classification of materials and topography.
Transitman 2 Assistants	Cross-sections.
Levelman 2 Assistants	Cross-sections.

Extra men moving camp, odd jobs, etc.

The first stage of the work varies in speed from ½ to 3 miles per ay, depending on the character of the county. Three-fourths ile per day is a fair average for ordinary mountain work.

The second stage should make a speed of from 1 to 2 miles per ay. A fair average is about 1½ miles per day.

Allowing for unavoidable loss of time, moving camp, etc., 10 miles month for an eight-man party is a fair average when they are oing first-class work.

Cost of Survey.—The cost of first-class complete mountain road cation surveys runs from $75 to $150 per mile exclusive of raiload transportation to the job, allowing $150 per month for the cating engineer, $120 per-month for transitman, $100 per month

for leveler, and $70 to $90 for laborers, etc. Meals are furnishe free to the men at an average cost of 75 cts. per man per day exclu sive of labor, or about $1 to $1.30 per day including cooks salary.[1]

The average speed for a party of eight men is approximately 1 miles per month of completed survey, at an average cost of $100 t $120 per mile exclusive of railroad transportation. In easy fla country this speed can be easily doubled and the cost halved.

DEPRECIATION ON ENGINEERING EQUIPMENT PER MILE OF SURVE
(Assumed 50 miles of survey per season)

Quantity	Item	Value	Approx. Life, Years	Annual Depreciation and Repairs	Rental Charge per Mile Survey
1	Transit (mountain) tripod.	$300.00	10	$40.00	
1	Level (dumpy or Y)......	150.00	10	25.00	
1	Locke level..............	7.00	3	2.50	
2	Abney levels @ $16.50....	33.00	5	6.00	
3	100′ chains @ $12.00.....	36.00	2	18.00	
4	Range poles (8′ wooden) @ $2.25...............	9.00	2	5.00	
2	Level rods, Philadelphia 13′ extension...........	30.00	1	30.00	
2	Chain repair kits.........	20.00	5	4.00	
3	Metallic tape boxes, $2.45.	7.00	1	7.00	
6	Metallic fillers...........	6.00	1	6.00	
1	Set sounding bars (1¼″–1″ and ¾″ tool steel).....	10.00	10	1.00	
4	Plumb bobs.............	4.00	2	2.00	
2	Pocket compasses........	4.00	3	1.50	
1	Kodak 3-A..............	24.00	4	6.00	
1	Engineer's trunk.........	10.00	1	10.00	
	Totals.................	$650.00		$164.00	$3.30 (Say $3.0

* Marking crayon.

* Use a crayon having a large amount of oil, as it will last longer. "Sta On-All" is a good brand.

[1] These costs are for 1914 cost conditions. In 1926 costs are approximate double for salaries and subsistence.

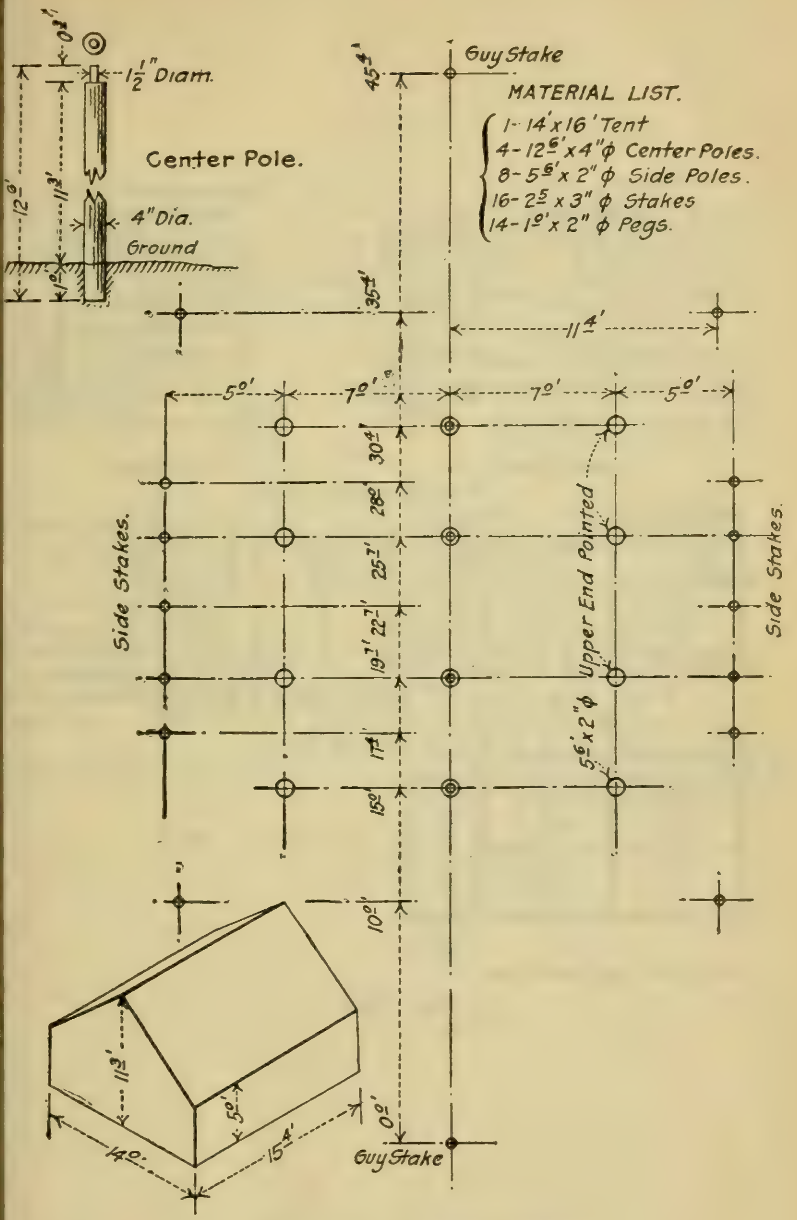


FIG. 285.—Layout diagram.

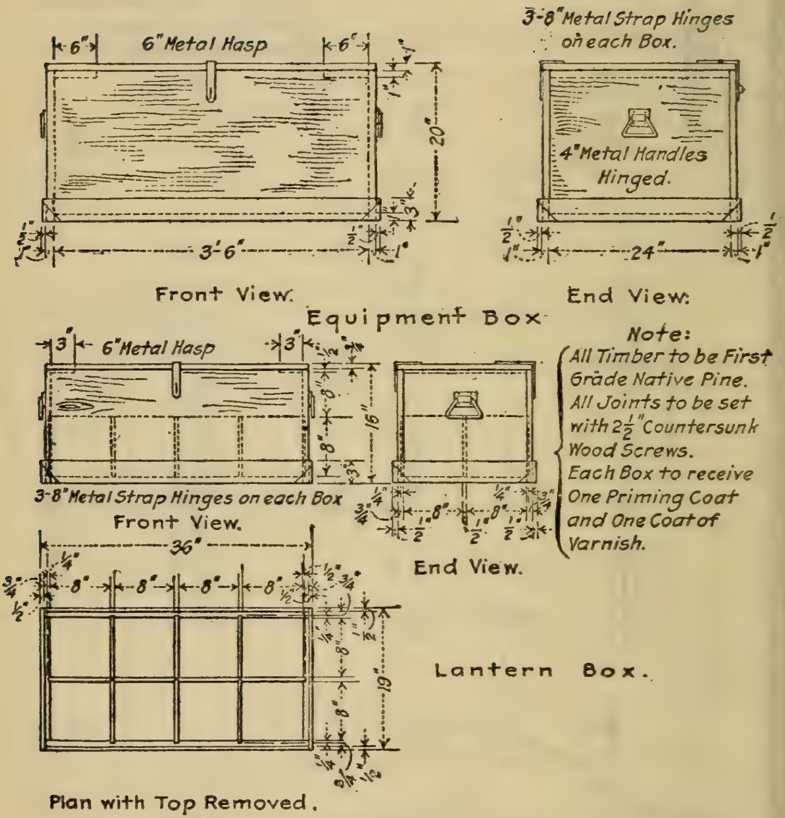

6" Metal Hasp
3-8" Metal Strap Hinges on each Box.
4" Metal Handles Hinged.
3'-6"
20"
24"
Front View.
End View.
Equipment Box
6" Metal Hasp
Note:
All Timber to be First Grade Native Pine.
All Joints to be set with 2½" Countersunk Wood Screws.
Each Box to receive One Priming Coat and One Coat of Varnish.
3-8" Metal Strap Hinges on each Box
Front View.
16"
36"
19"
End View.
Lantern Box.
Plan with Top Removed.

FIG. 286.

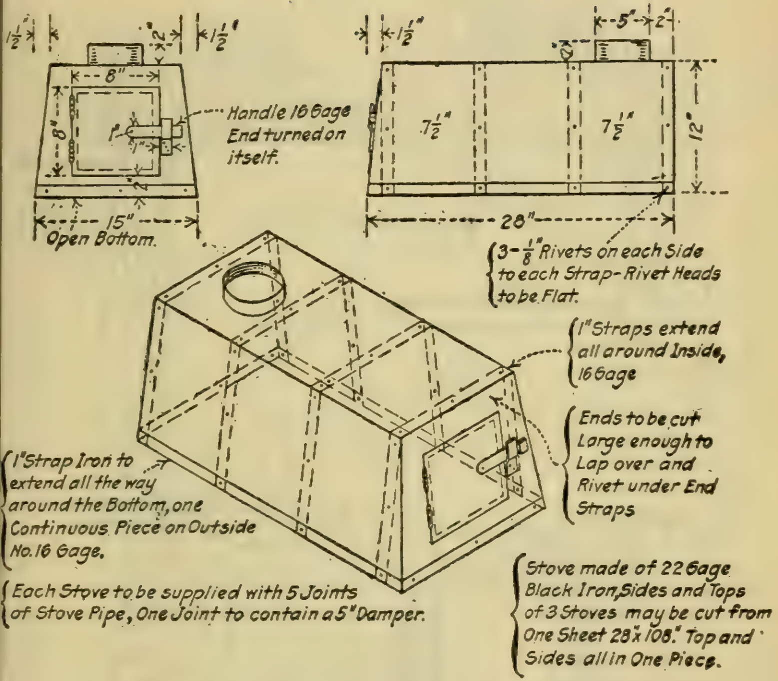


FIG. 287.—Tent heater

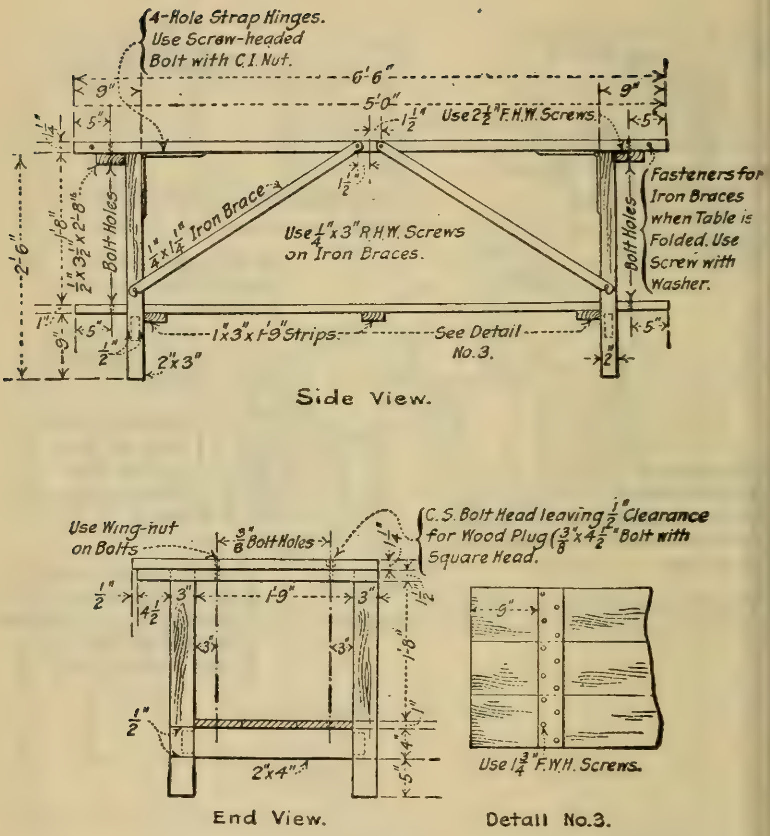


FIG. 288.—Folding kitchen camp table.

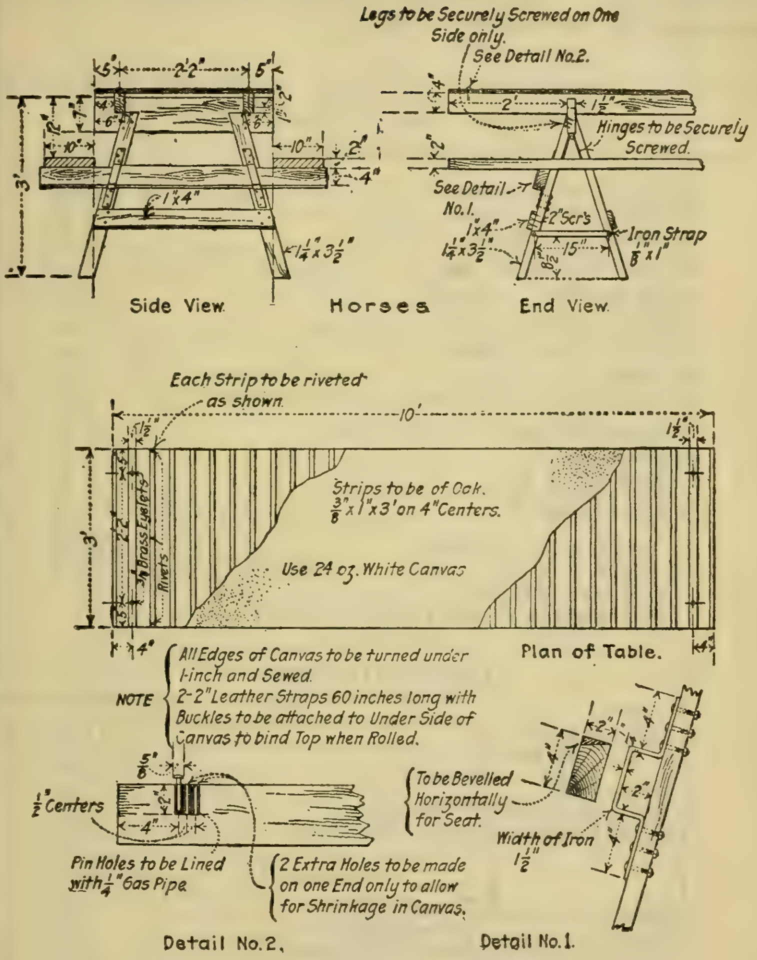


FIG. 289.—Portable mess tables.

Camp Equipment.—The authors would not have the temerity to recommend camp equipment any more than to dare advise a woman on cooking utensils. It is a delicate subject on which most campers have their own pet notions. The following lists are more in the nature of reminders than anything else and are based on outfits in ordinary use on mountain road surveys in the West where equipment can be moved by wagon.

TABLE 141.—OUTFIT FOR AN EIGHT- OR TEN-MAN PARTY ON LOCATION SURVEYS TABLE WARE

White enamelware dishes unless otherwise noted.

Item	Approx. Value
12 Cups, 3½" diameter	$2.00
12 Saucers, 6" "	1.80
3 Salt shakers (large) aluminum	0.60
1 " shaker (small) "	0.10
12 Table forks (retinned)	1.50
24 Tea spoons "	0.60
2 Meat platters, 16"	1.00
3 Pepper shakers (small) aluminum	0.60
1 " shaker (large) "	0.60
12 Plates, 9"	2.50
12 Table knives (retinned)	1.80
12 " spoons "	0.50
2 Water pitchers	1.50
2 Syrup "	1.50
12 Soup bowls, 5"	2.50
12 Sauce dishes, 5"	1.80
2 Sugar bowls, 6"	1.50
Total value tableware	$22.40
Say	$25.00

1916 Scale of Costs.
1926 would be approx. twice as much.

COOKING UTENSILS

Item	Approximate Value
1 Butcher knife 10"	$1.00
2 " knives 8"	1.00
1 " knife 18" (steel)	1.00
1 Bread board	0.50
2 Basting spoons, 14" (retinned)	0.20
2 Berlin kettles, 10 quart (aluminum)	3.00
3 " " 6 " "	4.00
1 " " 5 " "	1.00
1 " " 4 " "	1.00
3 Bowls, 10" diameter earthenware	1.50
4 Buckets, 10 quart galvanized iron	1.50
1 Coffee boiler, 1½ gallon, gray enamel	0.70
1 " " 3 quart (aluminum)	10.00
2 Carving forks, wire (3 prong)	0.30
1 Cake turner (retinned, perforated)	0.10
3 Can openers	0.50
1 Collander, 9" (aluminum)	1.80
1 Dishpan, 17 quart (retinned)	0.75
1 " , 14 " "	0.60
3 Dippers, 1 pint "	0.50
1 Drip pan, 9"×11" "	0.25
1 " " 10"×12" "	0.25
1 " " 11"×16" "	0.25
12 Dish towels	2.00
1 Egg beater (family size)	0.15
2 Frying pans, 13" diameter steel	0.65

1	Frying pan 11½″ diameter steel	0.25
1	Flour sieve (tin) 2 quart	0.20
2	Funnels (large)	0.40
2	" (small)	0.10
1	Grater	0.10
1	Jar for bread yeast, 3 gallon	0.75
1	Iron griddle, 20″ × 12″ cast iron	2.50
1	Meat saw	1.80
1	" chopper	0.50
1	" grinder	1.50
1	" cleaver, 8″	1.50
1	Milk pan, 6 quart (retinned)	0.50
3	Paring knives	0.40
12	Pie tins	2.25
1	Quart cup (retinned)	0.30
1	Rolling pin, 2⅝″ × 10¾″	0.15
1	Stove pot	2.10
1	Skimmer (aluminum)	0.25
2	Soup ladles, 3″ diameter	0.40
3	Serving pans, 12″ diameter white enamel	1.75
4	" " 7″ " " "	1.75
1	Tea pot, 1 gallon white enamel	0.60
1	Cook stove, 6 hole range, 18″ × 18″ × 12″ oven, top 26″ × 31″ (30″ high), weight approx. 250 lb.	25.00
	Total cooking utensils	$77.75
	Say	$80.00

1016 Scale of Costs.
1926 would be approx. twice as much.

Hardware

	Item	Approx. Value
4	Axes, 3½ lb.	$6.00
4	" 1½ lb. with sheath (hand)	5.00
6	Axe handles	2.00
2	Brush hooks or machetes	3.00
1	Cold chisel, small, 6″	0.10
1	Carborundum stone	1.20
1	Claw hammer, standard, 16 oz	0.80
4	Camp beaters with 5 joints nestible pipe (Sibley)	16.00
2	Files, mill bastard, 8″	0.50
1	Hasp	0.50
5	Oil lanterns 1¼″–1½″ "wick Stalit"	5.00
3	Gasoline lanterns, "Quicklite"	17.00
2	Picks, railroad	2.50
2	Pick handles	1.60
1	Pliers, 7″ lineman's	1.10
5	Piece nestible stove pipe for cooking stove	1.05
1	Screw driver, 18″	0.40
3	Sheath blocks C. I., ¼″ or ¾″ rope	3.00
2	Shovels, sharp pointed, long handles	2.50
1	Saw, 4′, one man in case	3.20
2	Sledges, 8 lb.	2.50
6	" handles	2.40
1	Saw, 26″, 7 point, No. 7 Diston	1.80
4	Stove pipe protectors, asbestos	9.00
1	Tool grinder, No. 6 American	——
6	Boxes tacks, carpet, 8 oz.	0.50
	Nails, 8d and 20d	1.00
3	Balls twine	0.50
2	Tubs, 24″ diameter galvanized iron	2.50
1	Whetstone	0.10
1	Washboard brass, 10½″ × 11½″	0.60
4	Washbasins, enameled ware	1.00
100′	Wire baling	0.25
1	Wedge, splitting, No. 5 Truckee	1.10
1	Wrench, monkey, 8″	1.00
		$96.70
	Say	$100.00

1916 Scale of Costs.
1926 would be approx. twice as much.

Tents, Tables, and Miscellaneous

Item	Approx. Value
2 Tents, 14′ × 16′	$180.00
3 " 10′ × 12′	110.00
1 Tent, 7′ × 9′	20.00
1 Kitchen table (see Figure 87, page 442)	15.00
1 Canvas mess table (see Figure 88, page 443)	25.00
3 Equipment chests (see Figure 86, page 440)	40.00
1 Mess box with padlock	5.00
1 Lantern box (see page 440)	5.00
2 Lunch baskets	3.80
6 Canvas chairs	6.00
4 " saddle bags	16.00
4 " note book shoulder bags	6.00
2 " water bags, 2½ gal.	2.50
3 Canteens, 2 qt. with webbing and strap	5.00
100′ ¼″ rope	1.00
48 Clothes pins	0.20
1 Alarm clock	2.50
2 Scrub brushes, 1½″ × 4″	0.25
125′ ½″ rope	4.00
5 Yards oil cloth, white	1.40
2 Brooms	1.60
1 Spring balance, 50 lb.	0.40
1 Sailmaker's palm with needles, twine and wax	1.65
1 Shoemaker's outfit containing semi-steel, stand, 2 lasts and pegging awl	2.00
12 Hand towels	2.50
1 Medicine chest with remedies	30.00
	$486.80
Say	$500.00

1916 Scale of Costs.
1926 would be approx. twice as much.

Depreciation on Camp Equipment

Table ware	$ 25.00
Hardware	100.00
Cooking utensils	80.00
Tents, etc.	495.00
Total	$700.00

1916 Scale of Costs.
1926 would be approx. twice as much.

Allowing for ordinary wear, accident, loss etc., this equipment i[s] probably good for 3 years. Allowing 50 miles of survey pe[r] season for each party, which is a fair average, the equipment i[s] good for 150 miles of survey, or at the rate of $4.50 per mile, whic[h] is a reasonably close charge for the use of camp equipment on surve[y] work of this character.

TABLE 142.—SURVEY PARTY
Ration—(one man one day)

Article	Unit	Quantity
Fresh meat	pounds	0.70
Cured meat	"	0.30
Lard	"	0.14
Flour	"	0.70
Corn meal	"	0.05
Baking powder	"	0.02
Sugar	"	0.35
Coffee	"	0.05
Tea	"	0.01
Butter	"	0.14
Dried fruit	"	0.10
Rice, beans or hominy	"	0.10
Potatoes	"	1.00
Salt	"	0.04
Flav. extracts	ounces	0.03
Spices	"	0.05
Milk, condensed	cans	0.40
Canned fruits	"	0.18
Vegetables (fresh or canned)	pounds	0.50
Syrup	"	0.06
Pickles	"	0.03
Eggs	nos.	2½
Breakfast foods	pounds	0.08
*Miscellaneous cost		2½c.

* Miscellaneous includes, crackers, yeast, chile powder, soda, salad, oil, ıtsup, chocolate, lemons, soap, sapolio, candles, matches, oil, and wood. n allowance of 2½ cts. per ration should easily supply these items.

NOTE.—Fresh milk may be substituted for condensed at a rate of 1 qt. ır one can.

Cost of Ration.—The cost of feeding one man per day, including ɔok's salary, based on 5000 man-day rations in 1918 on western ıountain location surveys averaged $1.30.

PRELIMINARY INVESTIGATION OUTFIT

Where one man is traveling alone on foot and will be out of ɔuch with habitation for a day or so at a time a simple outfit ırried in a knapsack or pack basket will serve very satisfactorily.

1 Waterproof canvas sleeping bag	$15.00
1 Light belt ax	1.00
1 Small fry pan	0.25
1 Cup with long handle for heating water	0.25
Knife, fork, and spoon	0.50
Matches in bottle or waterproof case	0.10
Small emergency food supply	2.00
Personal supplies	
Canteen in arid regions	

This whole pack will not weigh over 30 lb. and can be easil carried.

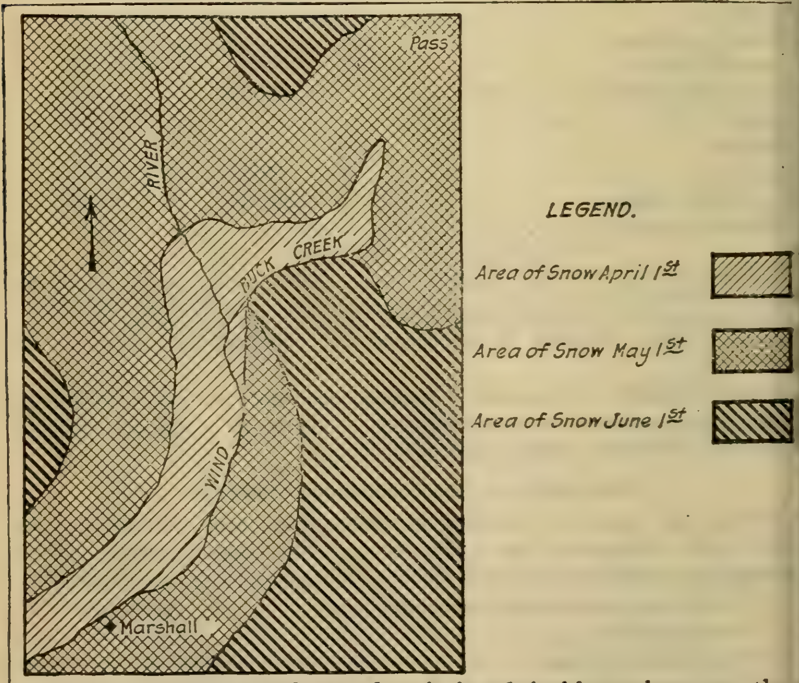
Camp Drafting Equipment (if desired).—Camp equipment i listed on *page* 900.

Survey Methods.—The chief of party should precede the men t the work and go over the entire line as outlined in the preliminar investigation report, picking out his camp sites and making al necessary arrangements for transportation of camp equipmen and supplies. He should also mark the base-line location for 2 o 3 miles so that when the party arrives there will be no dela in making camp and starting the line work.

First Stage of Survey

a. Tracing the location.
b. Running base line.
c. Running bench levels and base-line profile.

a. **Locating Line.**—This work is done by the locating enginee who considers all the principles of grade, alignment, etc., discusse in Chapter II. In high altitudes he pays particular attention t



NOTE.—This map shows that it is advisable to keep on the north side of Buck Creek and the west side of Wind River from the standpoint of avoiding snow. It also shows that the Pass was open by June 1st.

FIG. 290.

avoiding bad snow conditions which, in general, means avoiding north exposure as much as possible. Very often he can be helped in this part of the problem by making a snow map the spring preceding the survey. This is done by sketching in the areas where snow lies at different dates, say Apr. 1, May 1, June 1. When furnished with a map of this kind he avoids the areas of late snow where possible. Lacking a definite investigation for snow conditions the best available local data should be obtained from hunters, etc.

The different trial lines are traced with an Abney level in open country and a combination of Abney level and aneroid in timbered country. The line that he decides to adopt is marked at sufficiently close intervals either by blazing trees or tall stakes with flags on them, so that the base line party will have no difficulty in following the correct location. This work must be kept far enough ahead of the base line party so that there is no danger of the work of the main party becoming worthless by the line getting into a location which has to be abandoned and relocated.

When working on a ruling grade the line should be traced down hill from the highest point on the route. When working on a ruling grade the line in the field should always be traced at a less rate of grade than the maximum allowed; that is, if the maximum grade is set at 7% the locator should trace his line on a 6½ or 6% grade in order to give the designer a little leeway for economical variations from the field grade and yet keep within the maximum rate. When working on portions of the route requiring less than the ruling grade it makes no difference in which direction the line is traced so long as the base line is run in one direction with continuous stationing.

b. **Base Line.**—The base line follows the marked route of the location. It is a chained, transit line marked on the ground by stakes at least every 100′ well driven and marked with crayon (Stay-on-All) with the station or plus of each stake. Stakes are placed at each point on the line where a profile shot or cross-section will be required and should be well made and well driven so that they will remain in place at least 3 years. The transit points (angle points) are marked with well-driven hubs with tack centering; every third or fourth transit point should be permanently and carefully referenced by both azimuth and distance (see sample notes). The angles in the line are determined by transit readings and the bearings of the courses are recorded by azimuth, using true north as the zero azimuth. The use of true north as the reference line in these surveys is desirable on account of permitting a check on the accuracy of the transit work at any time, on account of retracing a lost line, and on account of right-of-way descriptions in localities laid out on the U. S. land system. The methods of determining true meridian by Polaris and solar observations are explained (pp. 912 to 932). In fairly flat or rolling topography the base line should follow the center line of the proposed improvement exactly and all curves at tangent intersections should be run in the field. It has been found from experience that for the topographic conditions mentioned the field men can pick the best location in easy country and also that where the center line is actu-

ally run and staked that it simplifies the work of cross-sectioning, the office design and the staking for construction.

On side-hill locations, however, or any kind of difficult work experience has shown that the field men cannot pick an exact center line which will be economical in design and that under these conditions it is a waste of time and money to run in curves. Under these conditions the base line is run as a series of tangents, keeping as close to the probable center line as possible and using short tangents in going around any natural features that will require a sharp curve in the finished road. Later when the cross-sections are taken they must be extended far enough from the line to allow

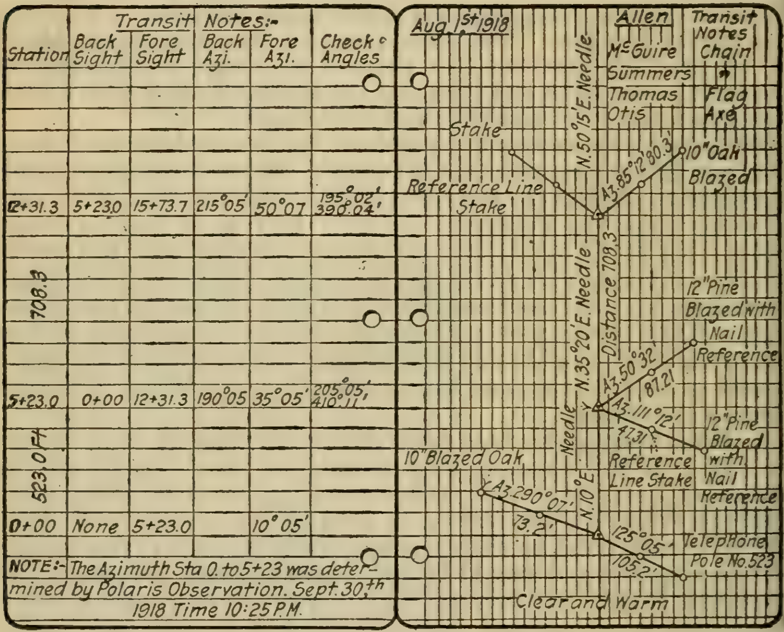
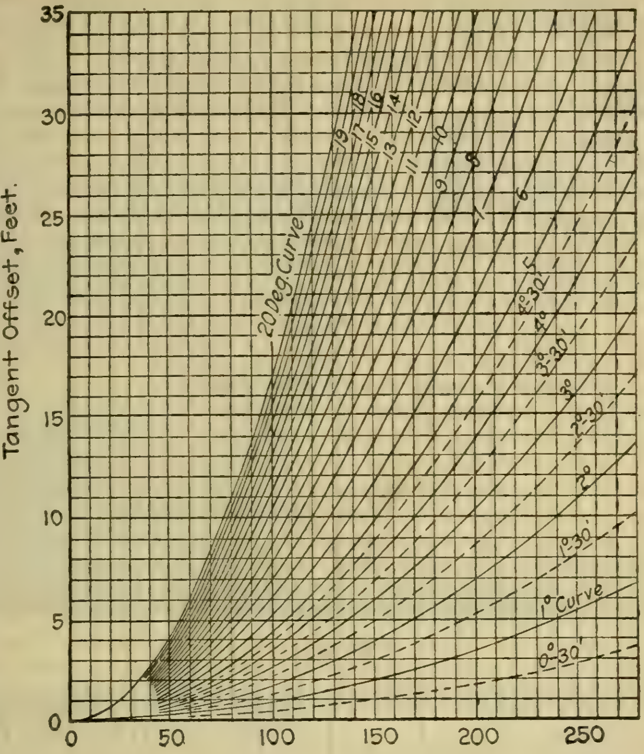


FIG. 291.

the designer to shift the center line from the base line as far as h desires as well as varying his vertical grade from the field grade This requires considerable extra work in cross-sectioning, as wil be taken up later, but is well worth while, as in difficult country a paper location is always more economical to construct than a fiel location.

Bench Levels.—Ordinary engineers spirit level work, readin turning points to nearest 0.01′. Benches are figured to neares 0.01′ in elevation (see sample notes, Fig. 293).

Permanent benches should be established at least every ½ mil and preferably at ¼-mile intervals. The datum for the level should be referred to U. S. Geological Survey datum if possible or lacking this reference a datum can be assumed, but in any cas the method of arriving at the elevation of the initial bench marl



The following instructions accompany the chart:

In measuring up to the P. I., leave temporary markers at enough points so that the line of the tangent can be readily located by eye. From the newly located P. I. turn off the desired deflection angle. Determine the degree of curve necessary to fit the conditions from the external and tangent length and take from table the tangent and length of curve, and record the station of the P.C. and P.T. Make the curve correction for difference in length of the sum of the tangents and distance on the curve at the P.I., and start measurements along next tangent, leaving temporary markers up to the P.T. of the curve. To lay out curve, start at the station or plus station near the P.C. and measure along the curve, using standard chord lengths, and using the offsets from tangent as read from chart, which increases as the distance from the P.C. or P.T. increases.

To be useful a chart of this kind should be drawn to a larger scale than we can reproduce in a handbook of this size and this has been inserted more to show a convenient method than for actual use. In the same manner a chart can be prepared for short radii curves from 40′ radius to 150′ radius that is very useful in mountain road location.

FIG. 292.

Sta.	Sample Bench Levels +	H.I.	−	Elev.		Aug 1, 1918 Remarks	Cate Thomas	Level Rod
B.M.O.				5248.21		U.S.G.S. Bench at Heber Bronze		
⊼	10.43	5258.64				Tablet in School House.		
T.P.			2.14	5256.50				
⊼	8.91	5265.41						
T.P.			7.22	5258.19				
⊼'	9.33	5267.52						
B.M No.1.			5.16	5262.36		Spike in Blazed Pine Tree 100' Rt of		
⊼	1.47	5263.83				Sta. 10+20		
T.P.			8.72	5255.11				

FIG. 293.

Station	Profile Level Turning Points +	−	H.I.	Profile Rod	Elev.	Aug 4, 1918 Remarks:	McGuire Thomas	Level Rod
B.M. O					5248.21	U.S.G.S. School House, Heber.		
⊼	10.20		5258.41					
0				11.2	47.2	Sta. 0 to 5 No Clearing or Grubbing.		
1				10.7	47.7			
2				9.5	48.9			
2+25				8.2	50.2			
3				5.1	53.3			
4				2.7	55.7	Put in 12" Cor. Iron Pipe.		
5				2.4	56.0			
T.P.		2.33			5256.08			
⊼	8.10		5264.18					
6				8.0	56.2	Clearing Sta. 5 to 10 Scrub Oak.		
6+25				6.9	57.3			
7				6.0	58.2			
8				5.3	58.9			
9				4.1	60.1			
10				3.1	61.1			
B.M. No.1.		1.85			5262.33	Bench Levels 5262.36 Use this		
⊼	5.27		5267.63	Corrected.		Elevation Forward.		

FIG. 294.

hould be fully explained in the notes. The computations of level iotes should be made in the field and checked each night.

Profile Levels.—These levels also act as a check on the bench evels and therefore require an independent line, preferably run in he opposite direction. The turns are read to the nearest 0.01′ nd the profile ground elevations of the base line to the nearest).1′. In case there is no radical difference in the two lines of evels (bench and profile) the profile levels are corrected to agree vith the bench levels at each bench and carried ahead on the bench levations. This is done so that there will be no cumulative differ-nce in the levels. An error of 0.1′ in running between benches s allowable (see Fig. 294 for sample profile level notes). Level omputations should be figured and checked each night and a pencil rofile plotted for the convenience of the locator.

Second Stage of Work

a. Cross-sections.
b. Topography.
c. Drainage.
d. Classification of materials.
e. Field drafting.

a. **Cross-sections.**—Cross-sections are the most important art of the detail work on survey. The tendency is to slight this art of the work, as it is tedious and uninteresting. The author as seen so much trouble experienced in the office design due to adequate cross-section field work that he wishes to emphasize the nportance of taking wide enough sections, particularly where a aper location is contemplated.

In level country where center line is exactly run, 30′ each side f the center line is enough.

In hilly country on side slopes averaging 25° where the center line s exactly located, 60′ each side of the line is enough.

Where the center line is not exactly located the engineer must se his judgment but, as a rule, it is not safe to use less than 100′ ach side of the line and care must be taken that they are taken xactly at right angles to the line.

For switchback turns or where a large variation from the survey ase line is probable, a careful stadia survey is desirable.

In flat country, cross-sections are taken with the engineer's level, od, and metallic tape in a similar way to the methods described the first of this chapter for high-class improvements.

In rough country they are generally taken with a hand level, od, and tape and each section is referred to the profile ground levation of the base line (see sample notes, Fig. 295). The abso-ite elevation of each point is figured from the base-line ground levation. This is important, as, while it entails more field com-utation, they can be done at night, and by the use of the absolute levations the office and design work is made simpler, cheaper, nd more accurate. Experience has demonstrated that the iethod of absolute elevations for cross-sections is much superior nd cheaper in the end than relative elevations. In very rough

country transit stadia cross sections are the cheapest and mos reliable preliminary survey method.

Cross-sections are taken at all breaks in the profile and in uniforr topography at least every 100′ and preferably at shorter intervals

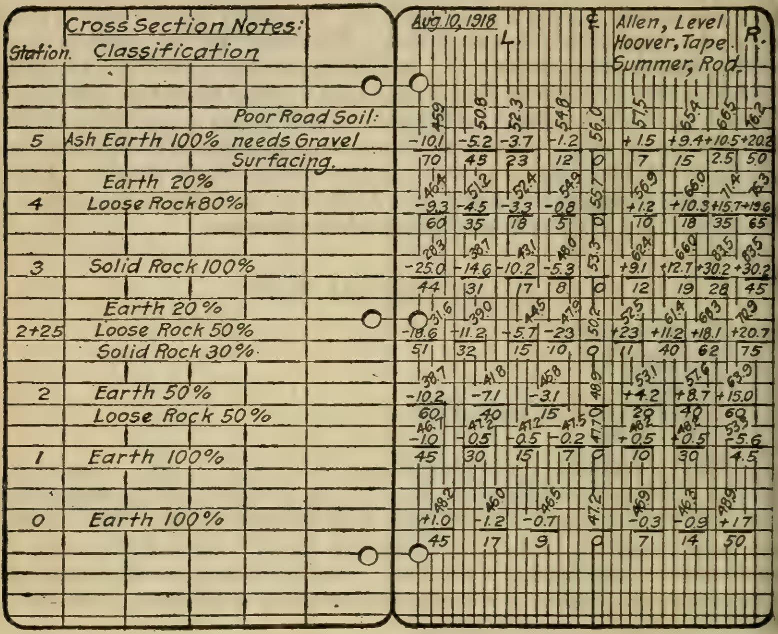


FIG. 295.

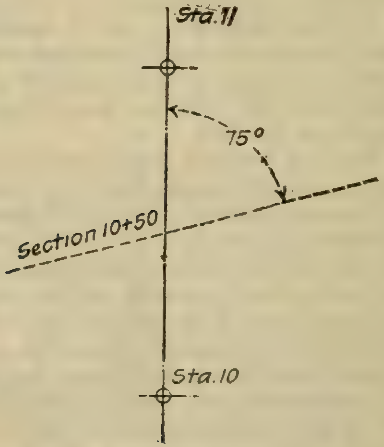


FIG. 295A.

Special cross-sections are taken for all drainage crossings anc show the skew angle of the proposed structure (see Fig. 295A).

Cross-section notes should be computed and checked each night.

b. **Topography.**—Taken in the same manner as previously escribed (see sample notes, Fig. 296).

c. **Drainage.**—Field drainage notes on new locations must be etailed and specific, as the recommendations determine the office esign absolutely; there is no possibility of the designer checking he conclusions.

Such notes should be made personally by the chief of party and hould indicate exactly where he wants the culverts or bridges

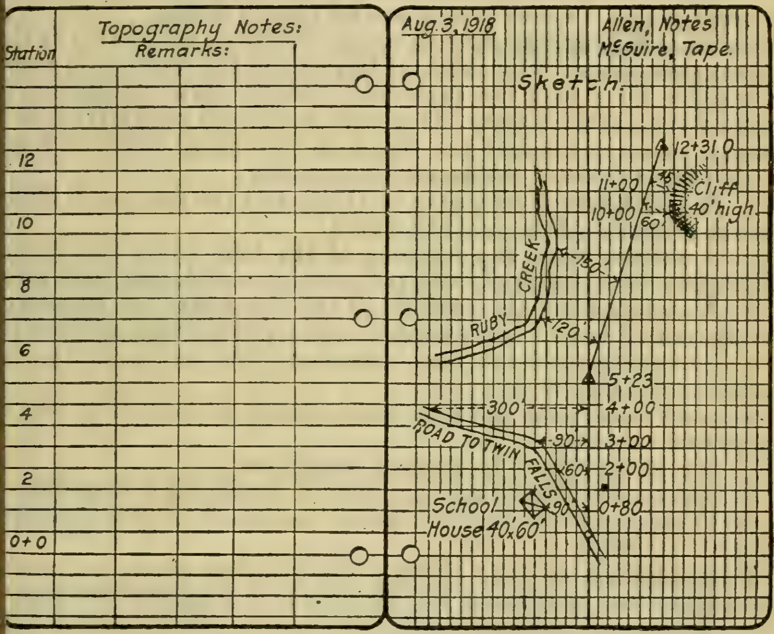


FIG. 296.

aced and the size of opening of the structure. He uses the rinciples discussed in the chapter on Drainage, and determines ie size of waterway either from the physical evidence of high water from the area of the drainage basin. Areas can be run out by ıced, hand compass traverses, determining the divide lines with hand level, or can be plotted directly in the field on a small 9 15″ plane table.

The type of structure, as log, corrugated pipe, concrete box, etc., ıould be stipulated for each structure, as the field man is the only ıe who can decide on the best type, considering the local materials ıat are available.

d. **Classification of Material.**—The classification of material ıs a marked effect on office design and should be handled by the ıief. The expenditure of considerable time and money is justified determining the subsurface conditions within the probable mits of proposed excavation where there is reason to believe that

solid rock will be encountered. This is done by bar soundings anc test pits. Where the soil contains a large percentage of boulders bar soundings are of little value. As a rule, it is impracticable tc determine more than a general classification for the largest part o the distance unless rock outcrops show on the surface.

e. **Field Drafting.**—The field drafting should be confined tc special problems desired by the chief and should only be don where there is doubt as to whether sufficient field data have beer obtained for the office design.

Complete design in the field is costly and is rarely as satisfactor as office design. Camp is no place for careful design.

Location Survey Reports.—A report should be worked up as th survey progresses. The object of this part of the record is to mak it possible for a man not personally familiar with the ground t make a reasonable design. It should include all information of general or special nature not shown in the survey notes such as

1. A description of the general topography.
2. A description of alternate locations and the reasons in deta for the selection of the route surveyed.
3. A statement of the portions of the line where the surve alignment should be rigidly adhered to and an undulating grade usec
4. A statement of the portions of the line where the alignmen can be shifted to fit a grade contour and a ruling grade adhered tc
5. The portions of the line where both line and grade can b varied in the final design.
6. Snow conditions and how bad exposure is avoided or why cannot be avoided.
7. Special designs to fit unusual conditions.
8. Special designs utilizing supplies of nearby local materials.
9. Photographs to illustrate special features or to give a gener idea of conditions.

Determination of True North.—The simplest method of dete mining the true meridian is by observation on Polaris at elongatio For all practical purposes fairly close results can be obtained b observation on Polaris or the sun at any time. The followin tables and explanation of simple methods are quoted or briefe from the Manual of the U. S. Geodetic Survey on Magnetism an the determination of the true meridian, and the Metro Manu of the Bausch & Lomb Optical Co.

Meridian by Polaris at Elongation.—For all practical roa survey purposes a determination of the meridian to the neare minute of angle is sufficiently close. For ½ hr. before elongatio to a half hour after elongation the azimuth of Polaris does not var over 30 sec. of angle, which gives plenty of time for check determin tions, and the element of exact standard time is of little importanc

DETERMINATION OF THE TRUE MERIDIAN

Because of the irregular distribution of the earth's magnetisn only an approximate value of the magnetic declination can be give for a place at which it has not been determined by observatio When a more accurate value is needed the true meridian must t determined, as the declination is the angle between the true meridia

and the magnetic meridian. This may be done by observations of the sun or Polaris. Five methods will be explained, three involving the use of a surveyor's transit and two requiring no instrumental equipment.

With care the methods involving the use of surveyor's transit should give the true meridian within 1 min. of arc, the other methods within 2 or 3 min., an accuracy ample for ordinary compass surveys.

a. With a Plumb Line and Peep Sight.—(1) By observations of Polaris at elongation; (2) by noting when Polaris and another star are in the same vertical plane.

b. With a Surveyor's Transit.—(3) By observations of Polaris at elongation; (4) by observations of Polaris at any hour; (5) by observations of the sun.

As a result of the rotation of the earth about its axis, Polaris, like other stars, appears to move in a circle about the pole of the heavens. It is said to be at culmination when it is in the vertical plane defined by the observer and the pole (upper culmination when it is above the pole) and at elongation when it reaches its extreme easterly and westerly positions with respect to the pole. At culmination its apparent motion is nearly horizontal, from east to west at upper culmination and from west to east at lower culmination. At elongation its apparent motion is nearly vertical, upward at eastern elongation and downward at western elongation.

The azimuth of Polaris is the angle at the observing station between the vertical plane through the pole and the one through the star. For a short time before and after elongation there is practically no change in the azimuth of Polaris and that time is usually selected for observing it for the purpose of determining the true meridian.

Approximate Method No I

Observations of Polaris at Elongation.—Attach the plumb line to a support situated as far above the ground as practicable, such as the limb of a tree or a piece of board fastened to a telegraph pole or a building, affording a clear view in a north and south direction.

The plumb bob may consist of any heavy material, a brick or a piece of iron or stone weighing 4 or 5 lb. serving to keep the plumb line straight and vertical as well as one of turned and finished metal.

Strongly illuminate the plumb line just below its support by a flash light or lantern, care being taken to obscure the source of light from the view of the observer.

For a peep sight nail two strips of tin or thin board with straight edges to a squared block of wood so that they will stand vertical about 1/16″ apart when the block rests on a horizontal surface.

Provide a rest for the peep sight at a convenient height above the ground, at such a distance south of the plumb line that when viewed through the peep sight Polaris will appear about a foot below the support of the plumb line. The top of this rest must be level and large enough to allow for sliding the peep sight east or west. The position of the rest should be fixed by trial the night preceding that set for observations, and it should be firmly secured in the proper position.

About 30 min. before the time of elongation, as given in Tal 143, bring the peep sight into the same line of sight with the plun line and Polaris.

The star will move off the plumb line to the east as it approach eastern elongation; to the west for western elongation. Move t peep sight to the west or east, as the case may be, keeping it in li with the star and the plumb line, until the star appears stationar thus indicating that it has reached elongation. The peep sight w then be secured in place by a clamp or weight and further operatio will be deferred until daylight.

By daylight place a slender rod at a distance of 200 or 300′ fro the peep sight and exactly in range with it and the plumb line; car fully measure this distance. (Text continued on Page 918.)

Table 143.—Local Civil Time of Upper Culmination Polaris in the Year 1931

Computed for 90°, or 6 hours west of Greenwich

Date	Civil time of upper culmination	Variation per day	Date	Civil time of upper culmination	Variation per day
	h. m. s.	m. s.		h. m. s.	m. s.
Jan. 1	18 54 26	−3 57	July 10	6 27 12	−3 5
Jan. 11	18 14 56	−3 57	July 20	5 48 05	−3 5
Jan. 21	17 35 25	−3 57	July 30	5 08 57	−3 5
Jan. 31	16 55 54	−3 57	Aug. 9	4 29 50	−3 5
Feb. 10	16 16 24	−3 57	Aug. 19	3 50 41	−3 5
Feb. 20	15 36 55	−3 57	Aug. 29	3 11 31	−3 5
Mar. 2	14 57 27	−3 57	Sept. 8	2 32 21	−3 5
Mar. 12	14 18 00	−3 57	Sept. 18	1 53 10	−3 5
Mar. 22	13 38 36	−3 56	Sept. 28	1 13 57	−3 5
Apr. 1	12 59 14	−3 56	Oct. 8	0 34 42	−3 5
Apr. 11	12 19 54	−3 56	Oct. 17	23 55 25	−3 5
Apr. 21	11 40 36	−3 56	Oct. 27	23 16 07	−3 5
May 1	11 01 21	−3 56	Nov. 6	22 36 47	−3 5
May 11	10 22 06	−3 55	Nov. 16	21 57 25	−3 5
May 21	9 42 54	−3 55	Nov. 26	21 18 01	−3 5
May 31	9 03 44	−3 55	Dec. 6	20 38 35	−3 5
June 10	8 24 34	−3 55	Dec. 16	19 59 08	−3 5
June 20	7 45 27	−3 55	Dec. 26	19 19 40	−3 5
June 30	7 06 19	−3 55	Jan. 5, 1932	18 40 10	−3 5

Table 143A.—Mean Time Interval between Upper Culmination and Elongation

Latitude	Time interval	Latitude	Time interval	Latitude	Time interval	Latitude	Time interval
°	h. m.	°	h. m.	°	h. m.	°	h. m.
10	5 58.2	35	5 56.1	48	5 54.3	58	5 52.
15	5 57.9	40	5 55.4	50	5 53.9	60	5 51.
20	5 57.4	42	5 55.2	52	5 53.6	62	5 51.
25	5 57.0	44	5 54.9	54	5 53.2	64	5 50.
30	5 56.5	46	5 54.6	56	5 52.8		

FIG. 297.

(Between Pages 914 and 91

Footnote for Tables 143, 143A.

ern elongation precedes and western elongation follows uppe ation by the time interval given in Table 143A. Lowe ation precedes or follows upper culmination by 11^h $58^m.0$. ıld be noted that there are two upper culminations on one October (15th in 1931) and two lower culminations in April n 1931). There are also two western elongations on one day ıary and two eastern elongations on one day in July.

o Refer the Times in Table 143 to Other Years.—

	m.		m.
p to Mar. 1....	add 1.5	1936, on and after Mar. 1	add 0.1
n and after Mar. 1	subtract 2.4	1937................	add 1.8
....	subtract 0 8	1938................	add 3.5
....	add 0.8	1939................	add 5.2
....	add 2.4	1940, up to Mar. 1....	add 6.8
p to Mar. 1....	add 4.0	1940, on and after Mar. 1................	add 2.8

o Refer to Other Than the Tabular Days.—Subtract from the r the preceding tabular day the product of the variation per d the days elapsed, as given below:

Variation per day			Days elapsed	Variation per day		
3^m 57^s	3^m 56^s	3^m 55^s		3^m 57^s	3^m 56^s	3^m 55^s
m. s.	m. s.	m. s.		m. s.	m. s.	m. s.
3 57	3 56	3 55	6	23 42	23 36	23 30
7 54	7 52	7 50	7	27 39	27 32	27 25
11 51	11 48	11 45	8	31 36	31 28	31 20
15 48	15 44	15 40	9	35 33	35 24	35 15
19 45	19 40	19 35				

Refer to Any Other Than the Tabular Longitude (90°).—Add each 10° east of the ninetieth meridian or subtract $0^m.1$ for ° west of the ninetieth meridian.

Refer to Standard Time.—Add to the quantities in Table 143 nutes for every degree of longitude the place of observation of the standard meridian (60°, 75°, 90°, etc.). Subtract ie place is east of the standard meridian.

e **144** was computed using the mean declination of Polaris for nning of each year. A more accurate result will be obtained ying to the tabular values the following corrections, which on the difference between the mean and apparent place of .

nth	Correction	Month	Correction	Month	Correction
	′		′		′
y......	−0.6	May........	0.0	September	−0.2
ry.....	−0.5	June........	+0.1	October.......	−0.4
....	−0.4	July........	+0.1	November	−0.7
....	−0.2	August	0.0	December.....	− .9

TABLE 144.—AZIMUTH OF POLARIS AT ELONGATION, 1931 TO 1940

Latitude	1931		1932		1933		1934		1935		1936		1937		1938		1939		1940	
°	°	′	°	′	°	′	°	′	°	′	°	′	°	′	°	′	°	′	°	′
10	1	05.0	1	04.7	1	04.4	1	04.1	1	03.8	1	03.4	1	03.1	1	02.8	1	02.5	1	02.2
11	1	05.2	1	04.9	1	04.6	1	04.3	1	04.0	1	03.6	1	03.3	1	03.0	1	02.7	1	02.4
12	1	05.4	1	05.1	1	04.8	1	04.5	1	04.2	1	03.9	1	03.6	1	03.2	1	02.9	1	02.6
13	1	05.7	1	05.3	1	05.0	1	04.7	1	04.4	1	04.1	1	03.8	1	03.5	1	03.2	1	02.9
14	1	05.9	1	05.6	1	05.3	1	05.0	1	04.7	1	04.4	1	04.1	1	03.8	1	03.5	1	03.2
15	1	06.2	1	05.9	1	05.6	1	05.3	1	05.0	1	04.7	1	04.4	1	04.1	1	03.8	1	03.5
16	1	06.6	1	06.2	1	05.9	1	05.6	1	05.3	1	05.0	1	04.7	1	04.4	1	04.1	1	03.8
17	1	06.9	1	06.6	1	06.3	1	06.0	1	05.7	1	05.3	1	05.0	1	04.7	1	04.4	1	04.1
18	1	07.3	1	07.0	1	06.6	1	06.3	1	06.0	1	05.7	1	05.4	1	05.0	1	04.7	1	04.4
19	1	07.7	1	07.3	1	07.0	1	06.7	1	06.4	1	06.1	1	05.7	1	05.4	1	05.0	1	04.7
20	1	08.1	1	07.8	1	07.4	1	07.1	1	06.8	1	06.5	1	06.2	1	05.8	1	05.4	1	05.1
21	1	08.5	1	08.2	1	07.9	1	07.6	1	07.2	1	06.9	1	06.6	1	06.3	1	05.9	1	05.6
22	1	09.0	1	08.7	1	08.4	1	08.0	1	07.7	1	07.4	1	07.0	1	06.7	1	06.3	1	06.0
23	1	09.5	1	09.2	1	08.9	1	08.5	1	08.2	1	07.9	1	07.5	1	07.2	1	06.8	1	06.5
24	1	10.0	1	09.7	1	09.4	1	09.0	1	08.7	1	08.4	1	08.1	1	07.7	1	07.3	1	07.0
25	1	10.6	1	10.3	1	09.9	1	09.6	1	09.3	1	08.9	1	08.6	1	08.3	1	07.9	1	07.5
26	1	11.2	1	10.9	1	10.5	1	10.2	1	09.9	1	09.5	1	09.2	1	08.8	1	08.4	1	08.0
27	1	11.8	1	11.5	1	11.1	1	10.8	1	10.5	1	10.1	1	09.8	1	09.4	1	09.0	1	08.6
28	1	12.5	1	12.1	1	11.8	1	11.4	1	11.1	1	10.8	1	10.4	1	10.1	1	09.7	1	09.3
29	1	13.2	1	12.8	1	12.5	1	12.1	1	11.8	1	11.4	1	11.1	1	10.7	1	10.3	1	09.9
30	1	13.9	1	13.5	1	13.2	1	12.8	1	12.5	1	12.1	1	11.8	1	11.4	1	11.0	1	10.6
31	1	14.6	1	14.3	1	13.9	1	13.6	1	13.2	1	12.9	1	12.5	1	12.2	1	11.8	1	11.4
32	1	15.4	1	15.1	1	14.7	1	14.4	1	14.0	1	13.7	1	13.3	1	12.9	1	12.6	1	12.2
33	1	16.3	1	15.9	1	15.6	1	15.2	1	14.9	1	14.5	1	14.1	1	13.8	1	13.4	1	13.0
34	1	17.2	1	16.8	1	16.4	1	16.1	1	15.7	1	15.4	1	15.0	1	14.6	1	14.2	1	13.8

35	1 18.1	1 17.7	1 17.4	1 17.0	1 16.6	1 16.3	1 15.9	1 15.5	1 15.1	1 14.7
36	1 19.1	1 18.7	1 18.3	1 18.0	1 17.6	1 17.2	1 16.8	1 16.5	1 16.1	1 15.7
37	1 20.1	1 19.7	1 19.4	1 19.0	1 18.6	1 18.2	1 17.8	1 17.5	1 17.1	1 16.7
38	1 21.2	1 20.8	1 20.4	1 20.0	1 19.7	1 19.3	1 18.9	1 18.5	1 18.1	1 17.7
39	1 22.3	1 21.9	1 21.6	1 21.2	1 20.8	1 20.4	1 20.0	1 19.6	1 19.2	1 18.8
40	1 23.5	1 23.1	1 22.7	1 22.3	1 22.0	1 21.6	1 21.2	1 20.8	1 20.4	1 20.0
41	1 24.8	1 24.4	1 24.0	1 23.6	1 23.2	1 22.8	1 22.4	1 22.0	1 21.6	1 21.2
42	1 26.1	1 25.7	1 25.3	1 24.9	1 24.5	1 24.1	1 23.7	1 23.2	1 22.8	1 22.4
43	1 27.5	1 27.1	1 26.7	1 26.3	1 25.8	1 25.4	1 25.0	1 24.6	1 24.2	1 23.7
44	1 29.0	1 28.5	1 28.1	1 27.7	1 27.3	1 26.8	1 26.4	1 26.0	1 25.6	1 25.1
45	1 30.5	1 30.1	1 29.6	1 29.2	1 28.8	1 28.4	1 27.9	1 27.5	1 27.1	1 26.6
46	1 32.1	1 31.7	1 31.2	1 30.8	1 30.4	1 29.9	1 29.5	1 29.1	1 28.7	1 28.2
47	1 33.8	1 33.4	1 32.9	1 32.5	1 32.0	1 31.6	1 31.2	1 30.7	1 30.3	1 29.8
48	1 35.6	1 35.2	1 34.7	1 34.3	1 33.8	1 33.4	1 32.9	1 32.5	1 32.0	1 31.5
49	1 37.5	1 37.1	1 36.6	1 36.1	1 35.7	1 35.2	1 34.8	1 34.3	1 33.8	1 33.3
50	1 39.5	1 39.1	1 38.6	1 38.1	1 37.7	1 37.2	1 36.7	1 36.2	1 35.7	1 35.2

(Text continued from Page 914.)

Find from Table 144 the azimuth of Polaris for the year of obser vation and the latitude of the place.

Find from the table on page 918 the natural tangent of this angl and multiply it by the distance from the peep sight to the rod. Th product will be the distance to be laid off from the rod, to the wes in the case of eastern elongation, or to the east for western elongation to a point which with the peep sight will define the direction of th true meridian with a fair degree of accuracy. Set a stake at thi point and another exactly below the deep sight, if the meridian i needed for future use.

NATURAL TANGENT OF ANGLES FROM 1° 00′ TO 1° 50′

Angle	Tangent	Angle	Tangent	Angle	Tangent	Angle	Tangent	Angle	Tangent
° ′		° ′		° ′		° ′		° ′	
1 00	0.01746	1 10	0.02036	1 20	0.02328	1 30	0.02619	1 40	0.02910
01	0.01775	11	0.02066	21	0.02357	31	0.02648	41	0.02939
02	0.01804	12	0.02095	22	0.02386	32	0.02677	42	0.02968
03	0.01833	13	0.02124	23	0.02415	33	0.02706	43	0.02997
04	0.01862	14	0.02153	24	0.02444	34	0.02735	44	0.03026
05	0.01891	15	0.02182	25	0.02473	35	0.02764	45	0.03055
06	0.01920	16	0.02211	26	0.02502	36	0.02793	46	0.03084
07	0.01949	17	0.02240	27	0.02531	37	0.02822	47	0.03114
08	0.01978	18	0.02269	28	0.02560	38	0.02851	48	0.03143
09	0.02007	19	0.02298	29	0.02589	39	0.02881	49	0.03172
1 10	0.02036	1 20	0.02328	1 30	0.02619	1 40	0.02910	1 50	0.03201

Method No 2

Noting When Polaris and Another Star are in the Same Vertical Plane.—For places north of latitude 35°, the true meridian may be determined by taking advantage of the fact that two bright stars in the northern heavens across the meridian on opposite sides of the pole only a few minutes before Polaris. These stars are the ones known as Zeta (ζ) Ursæ Majoris or Mizar and Delta(δ) Cassiopeiæ. Their positions in the constellations are shown in the accompanying diagram page 920.

Select that one of the two stars which at the time of the year when observations are to be made passes the meridian below the pole. When the star passes the meridian above the pole it is too near the zenith to be used. Delta Cassiopeiæ is on the meridian below the pole at midnight about Apr. 10, and is, therefore, the proper star to use at that date and for 3 months before and after. For the other 6 months of the year Zeta Ursæ Majoris will be the proper star to use. In the long days of June and July the lower culmination of both stars occurs during daylight, so that the method cannot be used.

Using the apparatus described under Observations of Polaris at Elongation, keep the peep sight in line with the plumb line and Polaris until the selected star also appears upon the plumb line. Carefully note the time when this occurs. Then, by moving the peep sight, continue to preserve its alignment with Polaris and the plumb line (paying no further attention to the other star). At the expiration of 12.5 min. (in 1922) Polaris will be on the meridian and the peep sight and plumb line will then define a true north and south line, which may be permanently marked for future use. *For each year subsequent to 1922 the interval increases approximately half a minute.*

As the pole distance of Delta Cassiopeiæ is 35° and that of Zeta Ursæ Majoris is 40°, this method cannot be used for the southern part of the United States where the stars are below the horizon at lower culmination. See page 920 for Star diagram.

Usual Method No. 3

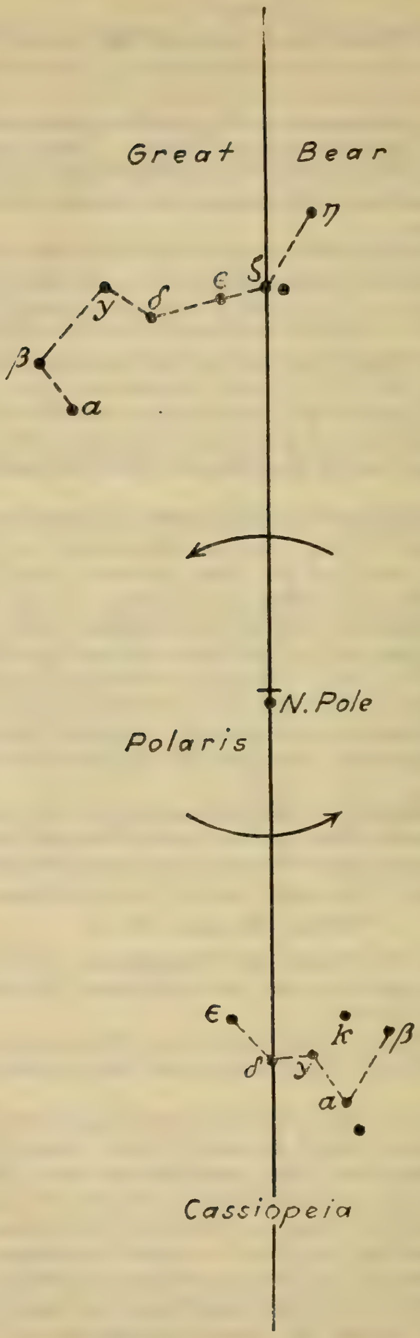
Observations of Polaris at Elongation.—With a surveyor's transit the true meridian may be determined by observing Polaris at elongation as follows:

Select a station for observing which affords a good view of the northern sky and with the ground clear for at least 100 yd. to the north.

If the station is to be used for determining the magnetic declination, care should be taken to have it well removed from electric car lines, buildings, and other possible sources of disturbance. If a meridian line is to be established for future use, the ends should be placed so that they may be protected from disturbance.

Mark the observing station in a suitable manner; for example, by a stone post with a drill hole in the top, set firmly in the ground. *Be sure the transit is in perfect adjustment* (*see page* 853).

About 30 min. before the time of elongation of Polaris, derived from Table 143, set up the transit with its vertical axis exactly


Great Bear
η
ζ
ε
δ
γ
β
α
N. Pole
Polaris
ε
k
β
δ
γ
α
Cassiopeia

over the station mark and carefully level the instrument. It is essential that the transverse axis of the telescope be horizontal. This should be tested in the daytime by pointing on the vertical edge of a house and noting whether the vertical cross-wire continues to coincide with the edge of the house as the telescope is turned in altitude.

Illuminate the cross-wires by the light from a bull's-eye lantern or a pocket flashlight directed obliquely into the object end of the telescope by an assistant.

Point the telescope at the star and clamp the horizontal circle. Keep the star covered by the vertical cross-wire by means of the tangent screw of the vernier plate, until a point is reached where it appears to move up or down along the wire without moving away from it, thus indicating that elongation has been reached.

Depress the telescope to the horizontal position; about 100 yd. north of the instrument drive a stake and mark a point on its top exactly coincident with the vertical wire of the telescope. This will require a second assistant and light. Turn the vernier plate 180° and again set the vertical wire on the star, clamp the horizontal circle, depress the telescope, and mark another point on the stake. The point midway between the two marks, with the point under the instrument, will define on the ground the vertical plane through Polaris at its eastern or western elongation, as the case may be.

Near elongation the azimuth of the star changes very slowly, not more than $0'.1$ in the 10 min. before or after elongation in the United States, so that there is plenty of time to make the second pointing after reversal, if there is no unnecessary delay.

By daylight lay off the proper angle taken from Table 144, to the east for western elongation and to the west for eastern elongation, and place a suitable marker to mark the north end of a meridian line of which the station marker will be the south end. The angle should be measured both before and after reversal, as in the case of the star.

METHOD NO. 4

Observations of Polaris at Any Hour.—The methods thus far described have the great advantage that an accurate knowledge of the time is not required, but they are not always convenient, as the elongation or culmination of Polaris does not always come at a convenient time for observing and the star may happen to be obscured just at that time.

The true meridian may be determined to the nearest minute of arc by observations of Polaris at any hour when the star is visible, provided the local mean time is known within 1 minute, as in the extreme case when Polaris is at culmination its azimuth changes $1'$ of arc in about 2 minutes of time in latitude 50°, and $1'$ of arc in about 3 minutes of time in latitude 20°. The standard time can usually be obtained at a telegraph office or directly by radio from the signals sent out from observatories. From this the local mean time may be derived by subtracting 4 min. of time for every degree of longitude west of the standard time meridian for the place of the observation (see page 914 for time zones) or adding 4 min. for every degree east of the standard meridian.

TABLE 145.—AZIMUTH OF POLARIS AT ALL HOUR ANGLES

Computed for declination 88° 53′ 25″. For hour angles 0^h to 12^h the star is west of north, and from 12^h to 24^h it is east of north.

Lat. / H.A.	10°	15°	20°	25°	30°	32°	34°	36°	38°	40°	42°	44°	46°	48°	50°	Lat. / H.A.
h. m.	° ′	° ′	° ′	° ′	° ′	° ′	° ′	° ′	° ′	° ′	° ′	° ′	° ′	° ′	° ′	h. m.
0 00	0 00.0	0 00.0	0 00.0	0 00.0	0 00.0	0 00.0	0 00.0	0 00.0	0 00.0	0 00.0	0 00.0	0 00.0	0 00.0	0 00.0	0 00.0	24 00
10	03.0	03.0	03.1	03.2	03.4	03.5	03.5	03.6	03.7	03.9	04.0	04.1	04.3	04.4	04.6	23 50
20	05.9	06.0	06.2	06.4	06.8	06.9	07.1	07.3	07.5	07.7	07.9	08.2	08.5	08.9	09.2	40
30	08.9	09.1	09.3	09.7	10.1	10.4	10.6	10.9	11.2	11.5	11.9	12.3	12.8	13.3	13.8	30
40	11.8	12.0	12.4	12.9	13.5	13.8	14.1	14.5	14.9	15.3	15.8	16.4	17.0	17.7	18.4	20
50	14.7	15.0	15.4	16.1	16.8	17.2	17.6	18.1	18.6	19.1	19.7	20.4	21.2	22.0	22.9	10
1 00	17.6	17.9	18.5	19.2	20.1	20.6	21.0	21.6	22.2	22.9	23.6	24.4	25.3	26.3	27.4	23 00
10	20.4	20.8	21.5	22.3	23.4	23.9	24.4	25.1	25.8	26.6	27.4	28.3	29.4	30.5	31.8	22 50
20	23.2	23.7	24.4	25.4	26.6	27.2	27.8	28.5	29.3	30.2	31.2	32.2	33.4	34.7	36.2	40
30	26.0	26.5	27.3	28.4	29.7	30.4	31.1	31.9	32.8	33.8	34.9	36.0	37.4	38.8	40.5	30
40	28.7	29.3	30.1	31.3	32.8	33.5	34.3	35.2	36.2	37.3	38.5	39.8	41.3	42.9	44.7	20
50	31.3	32.0	32.9	34.2	35.8	36.6	37.5	38.5	39.5	40.7	42.0	43.5	45.1	46.8	48.8	10
2 00	33.9	34.6	35.6	37.0	38.8	39.7	40.6	41.7	42.8	44.1	45.5	47.0	48.8	50.7	52.8	22 00
10	36.4	37.2	38.3	39.8	41.7	42.6	43.6	44.8	46.0	47.4	48.9	50.5	52.4	54.5	0 56.7	21 50
20	38.9	39.7	40.9	42.5	44.5	45.5	46.6	47.8	49.1	50.5	52.1	53.9	55.9	0 58.1	1 00.5	40
30	41.3	42.1	43.4	45.1	47.2	48.3	49.4	50.7	52.1	53.6	55.3	0 57.2	0 59.3	1 01.6	04.2	30
40	43.6	44.5	45.8	47.6	49.8	50.9	52.1	53.5	55.0	56.6	0 58.4	1 00.4	1 02.6	05.0	07.8	20
50	45.8	46.8	48.1	50.0	52.4	53.5	54.8	56.2	0 57.7	0 59.4	1 01.3	03.4	05.7	08.3	11.2	10
3 00	47.9	48.9	50.4	52.3	54.8	56.0	57.3	0 58.8	1 00.4	1 02.2	04.1	06.3	08.7	11.4	14.5	21 00
10	50.0	51.0	52.5	54.5	57.1	0 58.4	0 59.7	1 01.3	02.9	04.8	06.8	09.1	11.6	14.4	17.6	20 50
20	51.9	53.0	54.5	56.6	0 59.3	1 00.6	1 02.0	03.6	05.3	07.3	09.4	11.8	14.4	17.3	20.6	40
30	53.7	54.9	56.5	0 58.6	1 01.4	02.8	04.2	05.8	07.6	09.6	11.8	14.3	17.0	20.0	23.4	30
40	55.5	56.6	0 58.3	1 00.5	03.4	04.8	06.3	08.0	09.8	11.9	14.1	16.6	19.4	22.5	26.0	20
50	57.1	58.3	1 00.0	02.3	05.2	06.7	08.2	10.0	11.8	14.0	16.3	18.8	21.7	24.9	28.4	10

4 00	0 58.7	0 59.9	01.0	03.9	07.0	08.4	10.0	11.8	13.7	15.9	18.3	20.9	23.8	27.1	30.7	20 00
10	1 00.1	1 01.3	03.1	05.4	08.6	10.0	11.7	13.5	15.5	17.7	20.1	22.8	25.8	29.1	32.8	19 50
20	01.4	02.6	04.4	06.8	10.0	11.5	13.2	15.0	17.1	19.3	21.8	24.5	27.6	31.0	34.8	40
30	02.6	03.8	05.6	08.1	11.3	12.9	14.6	16.4	18.5	20.8	23.3	26.1	29.2	32.7	36.5	30
40	03.6	04.9	06.7	09.2	12.5	14.1	15.8	17.7	19.8	22.1	24.7	27.5	30.7	34.2	38.1	20
50	04.5	05.9	07.7	10.2	13.6	15.2	16.9	18.8	20.9	23.3	25.9	28.8	32.0	35.5	39.5	10
5 00	05.4	06.7	08.6	11.1	14.5	16.1	17.8	19.8	21.9	24.3	26.9	29.8	33.1	36.6	40.6	19 00
10	06.1	07.4	09.3	11.9	15.3	16.9	18.6	20.6	22.7	25.1	27.8	30.7	34.0	37.6	41.6	18 50
20	06.6	08.0	09.9	12.5	15.9	17.5	19.3	21.2	23.4	25.8	28.5	31.4	34.7	38.3	42.4	40
30	07.1	08.4	10.3	12.9	16.4	18.0	19.8	21.7	23.9	26.3	29.0	32.0	35.3	38.9	43.0	30
40	07.4	08.7	10.6	13.2	16.7	18.3	20.1	22.1	24.3	26.7	29.4	32.4	35.6	39.3	43.4	20
50	07.6	08.9	10.8	13.4	16.9	18.5	20.3	22.3	24.5	26.9	29.6	32.5	35.8	39.5	43.6	10
6 00	07.6	08.9	10.8	13.5	16.9	18.5	20.3	22.3	24.5	26.9	29.6	32.5	35.8	39.5	43.6	18 00
10	07.5	08.8	10.7	13.4	16.8	18.4	20.2	22.2	24.4	26.8	29.4	32.4	35.7	39.3	43.4	17 50
20	07.3	08.6	10.5	13.1	16.5	18.1	19.9	21.9	24.1	26.5	29.1	32.1	35.3	38.9	43.0	40
30	07.0	08.3	10.2	12.7	16.1	17.7	19.5	21.4	23.6	26.0	28.6	31.5	34.8	38.4	42.4	30
40	06.5	07.8	09.7	12.2	15.6	17.2	18.9	20.8	23.0	25.4	28.0	30.8	34.1	37.6	41.6	20
50	05.9	07.2	09.1	11.6	14.9	16.5	18.2	20.1	22.2	24.6	27.2	30.0	33.2	36.7	40.6	10
7 00	05.2	06.5	08.3	10.8	14.1	15.6	17.3	19.2	21.3	23.6	26.2	29.0	32.1	35.6	39.4	17 00
10	04.4	05.6	07.4	09.9	13.1	14.6	16.3	18.2	20.2	22.5	25.0	27.8	30.9	34.3	38.1	16 50
20	03.5	04.7	06.4	08.8	12.0	13.5	15.1	17.0	19.0	21.2	23.7	26.4	29.5	32.8	36.6	40
30	02.4	03.6	05.3	07.6	10.7	12.2	13.8	15.6	17.6	19.8	22.2	24.9	27.9	31.2	34.9	30
40	1 01.2	02.3	04.0	06.3	09.3	10.8	12.4	14.1	16.1	18.2	20.6	23.2	26.1	29.4	33.0	20
50	0 59.9	1 01.0	02.6	04.9	07.8	09.3	10.8	12.5	14.4	16.5	18.8	21.4	24.2	27.4	30.9	10
8 00	58.5	59.5	1 01.1	03.3	06.2	07.6	09.1	10.8	12.6	14.7	16.9	19.4	22.2	25.3	28.7	16 00
10	56.9	58.0	0 59.5	1 01.7	04.5	05.8	07.3	08.9	10.7	12.7	14.9	17.3	20.0	23.0	26.3	15 50
20	55.3	56.3	57.8	0 59.9	02.6	03.9	05.3	06.9	08.6	10.5	12.7	15.0	17.6	20.5	23.7	40
30	53.5	54.5	56.0	58.0	1 00.6	1 01.8	03.2	04.7	06.4	08.3	10.3	12.6	15.1	17.9	21.0	30
40	51.7	52.6	54.0	55.9	0 58.5	0 59.7	1 01.0	02.5	04.1	05.9	07.9	10.1	12.5	15.2	18.2	20
50	49.7	50.6	52.0	53.8	56.2	57.4	58.7	1 00.1	1 01.7	03.4	05.3	07.4	09.7	12.3	15.2	10
9 00	47.7	48.6	49.8	51.6	53.9	55.0	56.3	0 57.6	0 59.1	1 00.8	1 02.6	04.6	06.8	09.3	12 1	15 00
10	45.6	46.4	47.6	49.3	51.5	52.6	53.7	55.0	56.5	0 58.0	0 59.8	1 01.7	03.8	06.2	08.8	14 50
20	43.3	44.1	45.3	46.9	49.0	50.0	51.1	52.3	53.7	55.2	56.8	0 58.6	1 00.7	1 02.9	05.4	40
30	41.0	41.8	42.9	44.4	46.4	47.3	48.4	49.5	50.8	52.2	53.8	55.5	0 57.4	0 59.6	1 01.9	30
40	38.7	39.4	40.4	41.8	43.7	44.6	45.6	46.7	47.9	49.2	50.7	52.3	54.1	56.1	0 58.3	20
50	36.2	36.9	37.8	39.2	40.9	41.8	42.7	43.7	44.8	46.1	47.4	48.9	50.6	52.5	54.6	14 10

TABLE 145.—*Continued*

H.A. \ Lat.	10°	15°	20°	25°	30°	32°	34°	36°	38°	40°	42°	44°	46°	48°	50°	Lat. / H.A.
h. m.	° ′	° ′	° ′	° ′	° ′	° ′	° ′	° ′	° ′	° ′	° ′	° ′	° ′	° ′	° ′	*h. m.*
10 00	33.7	34.3	35.2	36.5	38.1	38.9	39.7	40.6	41.7	42.9	44.1	45.5	47.1	48.8	50.8	14 00
10	31.1	31.7	32.5	33.6	35.2	35.9	36.6	37.5	38.5	39.6	40.7	42.0	43.5	45.1	46.9	13 50
20	28.5	29.0	29.7	30.8	32.2	32.8	33.5	34.3	35.2	36.2	37.3	38.5	39.8	41.2	42.9	40
30	25.8	26.3	26.9	27.9	29.1	29.7	30.4	31.1	31.9	32.8	33.8	34.8	36.0	37.3	38.8	30
40	23.1	23.5	24.1	24.9	26.0	26.5	27.1	27.8	28.5	29.3	30.2	31.0	32.2	33.3	34.7	20
50	20.3	20.6	21.2	21.9	22.9	23.3	23.8	24.4	25.0	25.7	26.5	27.3	28.3	29.3	30.5	10
11 00	17.5	17.7	18.2	18.8	19.7	20.1	20.5	21.0	21.5	22.1	22.8	23.5	24.3	25.2	26.2	13 00
10	14.6	14.8	15.2	15.8	16.5	16.8	17.2	17.6	18.0	18.5	19.1	19.7	20.3	21.1	21.9	12 50
20	11.7	11.9	12.2	12.6	13.2	13.5	13.8	14.1	14 4	14.8	15.3	15.8	16.3	16.9	17.6	40
30	08.8	08.9	09.2	09.5	09.9	10.1	10.3	10.6	10.9	11.2	11.5	11.8	12.3	12.7	13.2	30
40	05.9	06.0	06.1	06.3	06.6	06.7	06.9	07.1	07.3	07.5	07.7	07.9	08.2	08.5	08.8	20
50	02.9	03.0	03.1	03.2	03.3	03.4	03.5	03.5	03.6	03.7	03.8	04.0	04.1	04.2	04.4	10
12 00	0 00.0	0 00.0	0 00.0	0 00.0	0 00.0	0 00.0	0 00.0	0 00.0	0 00.0	0 00.0	0 00.0	0 00.0	0 00.0	0 00.0	0 00.0	12 00

The selection and marking of the observing station and the adjustment of the theodolite will be done as in the case of observations of Polaris at elongation. As the observations are to be made when the azimuth of the star is changing, it will be preferable to provide an azimuth mark, such as a light showing through a slit in a box, and make a series of measures of the angle between the mark and the star. The light used to illuminate the cross-wires of the telescopes may be used also in reading the horizontal circle.

Begin by pointing on the mark and reading the horizontal circle. Point on the star, record the exact time and the reading of the circle. Turn the vernier plate 180° in azimuth and again point on the star, recording the time and circle reading as before. Finally, point on the mark again and read the circle. The number of pointings in a set may be increased or additional sets may be taken to secure greater accuracy. The azimuth of Polaris for the local mean time of observation will be derived from Table 145 in the manner explained below.

The following example explains the use of the table and the derivation of the hour angle of Polaris:

Position, latitude 36° 20′ N., longitude 80° 07′.5 or $5^h\ 20^m\ 30^s$ W. of Greenwich.

	°	′	″	h.	m.	s.
Time of observation, July 10, 1923, standard (75th meridian) mean time				8	52	40 p. m.
Reduction to local time				−	20	30
Local mean time				8	32	10
Reduction to sidereal time (table 3, American Ephemeris)				+	01	24
Sidereal time mean noon, Greenwich, July 10, 1923				7	09	33
Correction for longitude $5^h\ 20^m\ 30^s$ (table 3, American Ephemeris)				+	00	53
Local sidereal time				15	44	00
Apparent right ascension of Polaris, July 10, 1923				1	33	47
Hour angle before upper culmination				9	49	47
Declination for which Table 145 applies	88	53	25			
Apparent declination, July 10, 1923	88	53	19			
Decrease in declination			06			
Azimuth from Table 145 (interpolated)	0	44.0				
Correction for 6″ decrease in declination, table on page 927	+	0.1				
Computed azimuth	0	44.1 east of north.				

It is to be remembered that Polaris is east of the meridian for 12 hr. before, and west of the meridian for 12 hr. after, upper culmination.

Without the American Ephemeris the table may be conveniently used for obtaining the true meridian, in connection with Table 143 giving the approximate mean times of culminations of Polaris.

	h.	m.	s.
Time of observation, July 10, 1923, standard (75th meridian) mean time	8	52	40 p. m
Reduction to local mean time	−	20	30
Local mean time	8	32	10
Local mean time of upper culmination of Polaris (Table 143 and A)	18	20	18
Mean time of observation before upper culmination	9	48	08
Reduction to sidereal time	+	01	38
Hour angle before upper culmination	9	49	46

	°	′	″
Declination for which Table 145 applies	88	53	25
Declination July 15, 1923	88	53	19
Decrease in declination			06

	°	′
Azimuth from Table 145	0	44.0
Correction for 6″ decrease in declination, table on page 927	+	0.1
Computed azimuth	0	44.1 east of north.

Tables are generally given in books on surveying for reducin mean solar to sidereal time, but for this computation it is nea enough to consider the correction 10^s an hour, as the stars gain ver nearly 4 min. on the sun each day.[1]

Table 145 is taken from the American Ephemeris for 192 and was computed for a declination of Polaris of 88° 53′ 25″. Fo other declinations the corrections given in the following tabl should be applied. The correction is very nearly proportiona to the azimuth and amounts to a decrease of 0′.9 in azimuth for a increase of declination of 1′ for an azimuth of 60′. The abov declination is very nearly a mean value for the year 1922, th declination varying during the year as follows:

	°	′	″		°	′	″
January 15	88	53	35	July 15	88	53	0
February 15		53	33	August 15		53	0
March 15		53	26	September 15		53	1
April 15		53	17	October 15		53	2
May 15		53	08	November 15		53	3
June 15		53	03	December 15		53	4

The annual increase in declination of Polaris is about 16″.

[1] The sidereal correction always increases the hour angle.

CORRECTION TO TABULAR AZIMUTHS FOR OTHER DECLINATIONS

Azimuth.........	0′	20′	40′	60′	80′	100′	120′
Declination: ° ′ ″	′	′	′	′	′	′	′
88 53 25.........	0.0	0.0	0.0	0.0	0.0	0.0	0.0
53 30.........	0.0	0.0	−0.1	−0.1	−0.1	−0.1	−0.2
53 35.........	0.0	0.0	0.1	0.2	0.2	0.3	0.3
53 40.........	0.0	−0.1	0.2	0.2	0.3	0.4	0.5
53 45.........	0.0	0.1	0.2	0.3	0.4	0.5	0.6
53 50.........	0.0	0.1	0.3	0.4	0.5	0.6	0.8
53 55.........	0.0	0.2	0 3	0.5	0.6	0.8	0.9
54 00.........	0.0	0.2	0.4	0.5	0.7	0.9	1.1
54 05.........	0.0	0.2	0.4	0.6	0.8	1.0	1.2
54 10.........	0.0	0.2	0.5	0.7	0.9	1.1	1.4
54 15.........	0.0	0.2	0.5	0.8	1.0	1.3	1.5
54 20.........	0.0	0.3	0.6	0.8	1.1	1.4	1.7
54 25.........	0.0	−0.3	−0.6	−0.9	−1.2	−1.5	−1.8

METHOD No. 5

Solar Meridian by Direct Observation with an Ordinary Transit. Where the method of Polaris at elongation is not used, direct solar observation is the most convenient method of meridian determination, as, while it involves more computation and introduces more chances of error, the work can be done during daylight hours and the accuracy that can be attained (within 01′ of arc) with the usual facilities is close enough for all practical purposes of ordinary surveys.

There are a number of different forms of the fundamental formulas governing the determination; the following form has found considerable favor:

$$\tan^2 \tfrac{1}{2}A = \frac{\sin [S - (90^\circ - \text{alt.})] \sin [S - (90^\circ - \text{lat.})]}{\sin S \sin [S - (90^\circ - \text{dec.})]}.$$

In the formula, A is the angle of the sun from the true north measured to the right in the morning and to the left in the afternoon. S is one-half the sum of (90° − the observed altitude of the sun corrected for refraction) plus (90° − the latitude of the point of observation) plus (90° − the declination of the sun at the time of observation).

NOTE.—Notice carefully the sign of the declination. A south declination is *a* − declination which would make the expression (90° − (− south declination)) = 90° + south declination.

A solar ephemeris from which the sun's declination is found is necessary for the computations. All instrument makers publish small pocket editions each year which can be obtained from them for 10 cts.

An ordinary well-regulated watch set for standard time at the nearest telegraph office serves for the time determination on which

the sun's declination depends and any good transit with vertical circle can be used for observing the horizontal angle and altitude of the sun, but observers are cautioned that it must be in good adjustment and the observer must work with reasonable care.

If standard time is not available, mean local time can be determined by observation, as explained later on page 930.

The latitude of the point of observation can generally be determined closely enough from U. S. Geological Survey maps or Land Office maps, and if these are not available can be determined by observation as explained on page 929.

Longitude for standard time correction can be taken from any good map. If these are not available, determine local mean time by observation.

Considering all the different sources of error, time, latitude and observed altitude the best time of day to make the observation is between 9 and 10 a. m. and between 2 and 3 p. m.

Table 146 gives the correction for observed altitude due to atmospheric refraction. This correction is always minus as the sun always appears to be higher than it actually is.

Table 146.—Mean Refractions Due to Altitude
Barometer 30″, Thermometer 50°F.

App. Alt.	Ref.	App. Alt.	Ref.	App. Alt.	Ref.	App. Alt.	Ref.
5°	9′ 46″	10°	5′ 16″	20°	2′ 37″	50°	0′ 48″
6°	8′ 23″	12°	4′ 25″	25°	2′ 03″	60°	0′ 33″
7°	7′ 20″	14°	3′ 47″	30°	1′ 40″	70°	0′ 21″
8°	6′ 30″	16°	3′ 19″	35°	1′ 22″	80°	0′ 10″
9°	5′ 49″	18°	2′ 56″	40°	1′ 09″	90°	0′ 0″

A Table of Semidiameters of the Sun

Jan. 1, 16′18″	Apr. 1, 16′02″	July 1, 15′46″	Oct. 1, 16′01′
Feb 1, 16′16″	May 1, 15′54″	Aug. 1, 15′48″	Nov. 1, 16′09″
Mar. 1, 16′10″	June 1, 15′48″	Sept. 1, 15′53″	Dec. 1, 16′15′

Effect of Errors in Latitude and Declination on Meridiar Determination.—It is well to bear in mind the effect of wrong latitude, or time (which affects the declination), on your meridiar computations.

Table 147 prepared by Prof. J. B. Johnson of Washington University, St. Louis, Mo., reprinted in the Metro Manual of the Bausch & Lomb Optical Co., shows the effect of error in latitude and declination for different latitudes and different hours in the day.

[T]ABLE 147.—ERRORS IN AZIMUTH (BY SOLAR OBSERVATION) FOR 1′ ERRORS IN DECLINATION AND LATITUDE

Hour	For 1 Min. Error in Declination				For 1 Min. Error in Latitude			
	Lat. 30°	Lat. 40°	Lat. 50°	Lat. 60°	Lat. 30°	Lat. 40°	Lat. 50°	Lat. 60°
	Min.	Min.	Min.	Min.	Min.	Min.	Min.	Min.
11.30 A. M. 12.30 P. M.	8.85	10.00	11.92	14.07	8.87	9.92	11.82	13.56
11.00 A. M. 1.00 P. M.	4.46	5.04	6.01	7.68	4.31	4.87	5.81	6.37
10.00 A. M. 2.00 P. M.	2.31	2.61	3.11	4.00	2.00	2.26	2.69	3.46
9.00 A. M. 3.00 P. M.	1.63	1.85	2.20	2.83	1.15	1.31	1.56	2.00
8.00 A. M. 4.00 P. M.	1.33	1.51	1.80	2.31	0.67	0.75	0.90	1.15
7.00 A. M. 5.00 P. M.	1.20	1.35	1.61	2.07	0.31	0.35	0.42	0.54
6.00 A. M. 6.00 P. M.	1.15	1.31	1.56	2.00	0.00	0.00	0.00	0.00

Stated simply, this means that, if the observations are taken [b]etween 9 and 10 o'clock as recommended, for the most unfavor[a]ble conditions of fast-changing declination an error of time of 15 [m]in. will result in an error of 01′ of arc on the meridian computations.

It is well to check the latitude by observation unless your loca[ti]on is well fixed on a very reliable map. A simple method of lati[t]ude determination is quoted from the Metro Manual of the Bausch [&] Lomb Optical Co.

LATITUDE DETERMINATIONS

"Latitude may be variously determined by observing the transit of a star, [b]y a mean altitude of Polaris, or by a direct observation on the altitude of [t]he sun at apparent noon.

"Owing to the earth's annual motion in its orbit, the sun changes his [p]osition along the ecliptic with respect to the stars at a not altogether uni[fo]rm rate, so that some solar days are either longer or shorter than others.

"For the reason that a chronometer could not con[v]eniently be made to change its speed to suit this solar [p]henomenon, there has been established a uniform sys[te]m of time called 'mean solar time.' The difference [b]etween mean noon, when the sun should be on the [m]eridian, and apparent noon when the sun actually is [o]n the meridian, is called the 'Equation of Time.' The [ta]bular corrections will be found in the Ephemeris tables.

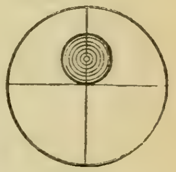


FIG. 298.

"Thus, in early November the sun has passed the [m]eridian more than 16 min. before mean noon. It is [al]ways well to begin latitude observations some 20 min. [b]efore local noon, although there will be seasons of the [y]ear when the sun will not attain its greatest altitude until [af]ter local noon.

"**Standard time** will also qualify the argument, but this should be studied [ou]t by reference to the map on page 914. In western Texas, for instance, [o]bservations need not begin until nearly 1 o'clock standard time; whereas in [E]rie, Pa., they should begin shortly after 11.

"**Procedure.**—Follow up the lower limb of the sun, and when the maximum [al]titude is found add the sun's semidiameter, as given on page 928, to the [re]ading on the vertical circle; subtract correction for atmospheric refraction,

as figured by interpolation from the table (p. 928), and correct this result t the sun's declination, adding if south and subtracting if north. The fin result is the colatitude or the polar distance (90° – latitude)."

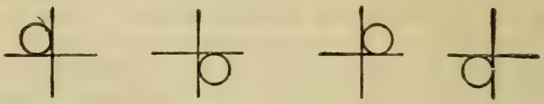
To find the latitude subtract the colatitude from 90°, *i.e.*, latituc = 90° – colatitude.

Time.—In case telegraphic standard time is not availab determine the meridian by Polaris at elongation and then the mea local time can be obtained by the transit of Polaris across the mer dian by referring to Table 143 (p. 914) or by the apparent sun tin when it crosses the meridian at noon connected to mean time a given in the Ephemeris referred to on page 927 which can l obtained from any instrument maker.

SOLAR MERIDIAN BY DIRECT OBSERVATION, PROCEDURE, AND EXAMPLE OF COMPUTATION

Procedure.—An ordinary transit with one-half vertical circle : good adjustment will give satisfactory results, although it is co venient to have a machine with a full vertical circle and a mask prismatic eyepiece for direct observation.

When using an ordinary transit remove the cap from the eyepie and then by focusing the eyepiece and objective lenses correct



Observation No.1., No.2., No.3., No.4.

a sharp well-defined image of both cross-wires and sun can be pr jected onto a piece of white paper held a few inches back the eyepiece. The vertical and horizontal angles to the sun ca then be read by bringing the image of the sun tangent to tl image of the vertical and horizontal wires simultaneously and tl time recorded. Two, four, or six observations are made as rapid as possible with the image of the sun alternately in opposi quadrants and the average time, average vertical angle, and avera horizontal angle used in the computations.

Example.—Solar meridian observations at Lima, Ohio, Jan. 1 1918.

Average time of four observations, 2.42 p. m. Central Standa time.

Average horizontal angle (mark to sun).....		132° 22′ 0
Average vertical angle to sun...............		16° 37′ 0
Longitude of Lima.........................		84° 07′ 0
Latitude of Lima..........................		40° 45′ 0
Observed altitude of sun..................		16° 37′ 0
Refraction correction......................		— 3′ 0
Corrected altitude.........................		16° 34′ 0
Latitude...................................		40° 45′ 0
Declination at time of observation...........	S.	20° 34′ 3

Declination Computation.—Observed standard time (central 90th meridian) 2.42 p. m. Lima is 5° 53′ east of the 90th meridian. To get the correct local mean time add to the recorded time 4 min. for each degree of longitude east of the 90th meridian or $4 \times 5.9° = 23.6$ min. (say 24 min.).

Correct local mean time of observation 3.06 p. m.

Take from the Ephemeris the sun's declination at Greenwich mean noon of Jan. 18, 1918 = S. 20° 38.9′.

Lima is 84° 07′ west of Greenwich, or its mean local time is 5 hr. and 36 min. earlier, that is, the local mean time of Lima at Greenwich mean noon is 6.24 a. m. and the sun's declination for 6.24 a. m. Lima local mean time is S. 20° 38.9′.

The declination is decreasing at the rate of 30″ per hour. The time of observation 3.06 p. m. local mean time is 8 hr. and 42 min. later than 6.24 a. m. and the declination for the time of observation is therefore:

Declination at 6.24 a. m. Lima	= S. 20° 38.9′
8.7 hr. × 0.5′ (30″ hourly change)	= — 4.3′
Declination at time of observation	= S. 20° 34.6′
	= S. 20° 34′ 36″
Say	= S. 20° 34′ 30″

It should be remembered that a south declination is a minus declination. Be careful of your signs in the following formula: Applying the formula

$$\tan^2 \tfrac{1}{2}A = \frac{\sin [S - (90° - \text{alt.})] \sin [S - (90° - \text{lat.})]}{\sin S \sin [S - (90° - \text{dec.})]}$$

$$S = \frac{(90° - 16° 34') + (90° - 40° 45') + (90° - (-20° 34' 33''))}{2}$$

$$S = \frac{73° 26' + 49° 15' + 110° 34' 30''}{2} = 116° 37' 45''$$

$$S - (90° - \text{alt.}) = 43° 11' 45''$$
$$S - (90° - \text{lat.}) = 67° 22' 45''$$
$$S - (90° - \text{dec.}) = 6° 03' 15''$$

log sin 43° 11′ 45″	= 9.835 3697
log sin 67° 22′ 45″	= 9.965 2348
colog sin (180° − 116° 37′ 45″) 63° 22′ 15″	= 0.048 6988
colog sin 6° 03′ 15″	= 0.976 8768
log tan² ½A =	2|20.826 1801
log tan ½A =	0.413 0900
½A = 68° 52′ 45″	
A = 137° 45′ 30″	

As the observation was in the afternoon the angle between the sun and true north is 137° 45′ 30″ to the west of north. The azimuth from the instrument to the sun is therefore 360° − 137° 45′ 30″ = 222° 14′ 30″.

The true azimuth from the instrument to the mark is therefore 222° 14′ 30″ − 132° 22′ = 89° 52′ 30″.

To mark the true meridian on the ground turn off an angle of 8ç 52′ 30″ to the left from the reference mark used in the observation.

The Ross Meridiograph.—If much meridian work is being don it will pay to obtain the Ross Meridiograph, which graphicall solves the solar meridian to the nearest minute. It is quick an simple to use and eliminates the one drawback of the direct observ: tion, namely, the extended computations.

STADIA MEASUREMENTS

An expert instrumentman with a first-class transit can get more a curate results in rough country, providing the atmospheric conditioı are steady, by the use of the stad method of measurement than by tl ordinary chaining of the average surv gang. The author has for a number years worked under a restriction of closure of less than 5.0′ to the mile, whi is better than can be attained by orc nary chainmen in hard topograph The method is quick and reliable and to be preferred in open country. Chai ing is to be preferred in heavy cutti or where curves must be run in.

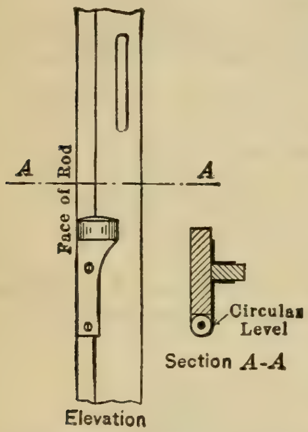


FIG. 299.—Sketch of circular plumbing level for stadia rods.

For an ordinary tangent prelimina survey the stadia method is very sat factory. To get good results, howev the observer should be expert. T ordinary garden variety of instrumeı man cannot use stadia successfully; should check his main line by both ba and foresight readings. He must ke his instrument in first-class shape a must use a rod with a fairly broad face with clear distinctive maı ings; this rod must be held steady and vertical, which can

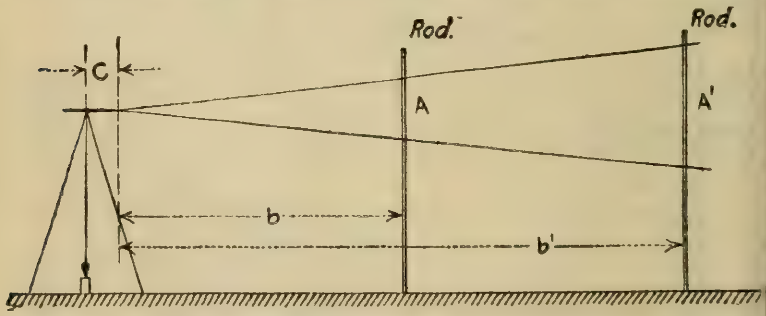


FIG. 300.

accomplished by the use of a small universal circular level attach to the rod, and steadiness can be secured by a short hand ı (about 4′ long) that the rodman uses as a shifting brace.

The transit must be steady, must have a first-class lense, and must be equipped with *fixed* stadia wires. Adjustable stadia wires are worthless if good work is required Distances between hubs should, as a rule, not exceed 500 to 600′ for close line measurements, but side slots can be taken up to 1500′.

The essential elements of the theory of stadia measurement are briefly as follows:

The measurement depends on the optical angle of the stadia wires. This angle is governed by the distance apart of the stadia wires. The rod intervals A and A' subtended between the stadia wires are directly proportional to the distances b and b' from the apex of the optical angle. The apex of this optical angle is always a certain fixed distance in front of the instrument and is different for different makes of transit. Call this distance C, which can be determined, as later explained, by test or is generally noted in instructions furnished by the instrument maker. The actual rod interval as read by the observer is therefore proportional to

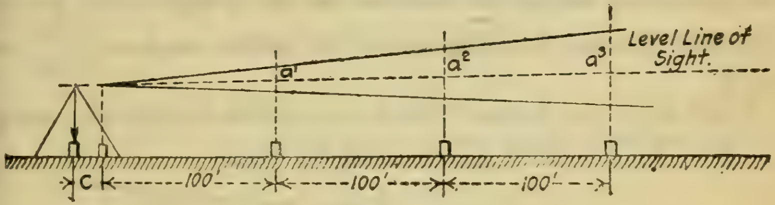


FIG. 301.

the distance from a point ahead of the instrument and not from the center of the transit. For close work, this distance C must be known and also the rod interval per 100′ of distance beyond the apex of the optical angle. The rod interval per 100′ of distance is desirably 1.0′ but unless unusual care is exercised in setting the wires it is rarely exactly this value. To determine the actual value of this interval proceed as follows:

Case 1.—Where the value of C is known.

NOTE.—C generally ranges between 0.75 and 1.25′.

Pick out a level line about 800 to 1000′ long. Drive a transit hub; place a foresight picket. Measure from the transit hub toward the foresight the distance C, which will be assumed in this case to be 1.25′, and drive a hub. This hub represents on the ground the apex of the optical angle. From this hub measure carefully with a steel chain 100′ and set a hub on line with the foresight and continue to set points at intervals of exactly 100′ until you have a test line 800 to 1000′ long.

Now level the telescope and read the rod intervals when the rod is held on each of the stakes and record this interval to the nearest fraction of a foot that you are sure you can actually see. As the length of sight increases it becomes less and less possible to determine the interval exactly, and when you are not certain of the reading to a 0.01′ stop attempting to lengthen the sight and you have practically determined the safe length of sight for actual

ine work that the instrument is capable of handling. To determine the rod interval record your readings and take the average value. Assume your rod intervals to be as follows:

a'	$0.997' \div 1 = 0.997$
a^2	$1.995' \div 2 = 0.9975$
a^3	$2.99' \div 3 = 0.9967$
a^4	$3.99' \div 4 = 0.9975$
a^5	$4.985' \div 5 = 0.997$
a^6	$5.97' \div 6 = 0.995$
a^7	$6.95' \div 7 = 0.993$
a^8	$8.02' \div 8 = 1.002$

This indicates that beyond 500′ the readings become uncertain and that about 600′ is the limit of practical line sight for close work. Good stadia work requires that the instrument man is perfectly honest with himself and recognizes his limitation when it is reached. The rod interval per 100′ is therefore 0.997 in this case and every foot on the rod *when the line of sight is level* means an actual distance from the apex of the optical angle of $\frac{1.000}{0.997} = 100.3'$.

To get the actual distance then for a level line of sight rod reading of 2.45′ multiply $2.45 \times 100.3 = 245.73'$.

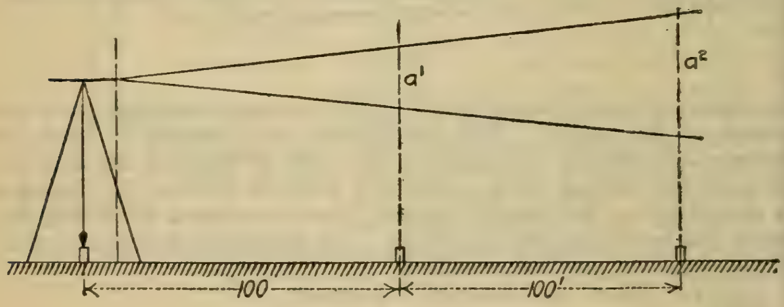


FIG. 302.

Say 245.7′ from the apex of the optical angle and the distance from the center of the instrument will be 245.7′ plus the constant C (1.25) equals 246.95′ from the center of the instrument.

The effect of the inclined line of sight will be discussed later.

Case 2.—Where the constant C is not known. To determine the constant C and the rod interval per 100′ of distance beyond the apex of the optical angle.

Measure a base line 800 to 1000′ long placing hubs every 100′ and every 10′ for the first 100′, but measuring these distances from the center of the instrument, as C is not known.

Set the transit up over the first hub and with a level line of sight read the stadia wire rod interval at each of the stakes on the line which are at actually measured known distances from the center of the instrument of 20′, 30′, 40′, 50′, etc., and 100′, 200′, 300′, etc.

The problem is to determine two unknown quantities, C the constant and X (the rod interval per 100′ of distance beyond the apex of the optical angle). According to Case 1, $\frac{1.00'}{X}$ = the actual distance beyond the apex represented by a rod interval of 1′. Therefore the constant C can be determined from two equations using the actual rod intervals at two different stakes. The constant C can be most accurately determined by short sights 20 to 40′ and the rod interval per 100′ from the longer sights 100 to 300′. The method is illustrated as follows, using rod readings taken at points 100′ and 200′ from the center of the instrument.

$$100' - C = \text{observed rod interval } a^1 \times \frac{1.00'}{X}$$

$$200' - C = \text{observed rod interval } a^2 \times \frac{1.00}{X}$$

Suppose the rod interval $a^1 = 0.9845$
Suppose the rod interval $a^2 = 1.9815$

$$100.0 - C = 0.9845\frac{1.00}{X}$$

$$200.0 - C = 1.9815\frac{1.00}{X}$$

call $\left(\frac{1.00}{X}\right)$ the symbol Y.

$$100.0 - C = 0.9845Y \qquad \text{Eq. (1)}$$
$$200.0 - C = 1.9815Y \qquad \text{Eq. (2)}$$

$$100.0 = 0.997\ Y \qquad \text{Subtract Eq. (1) from (2).}$$

$$Y = \frac{100.00}{0.997}$$
$$Y = 100.3'.$$

That is, a 1′ rod interval equals 100.3′ of distance beyond the apex of the optical angle.

To determine C, substitute this value of Y in Eq. (1).

$$100.0 - C = 0.9845 \times 100.3$$
$$-C = -100 + 98.75$$
$$C = 100 - 98.75$$
$$C = 1.25'.$$

Apply this principle to three or four sets of readings and take the mean values.

You now have the basic constants of the instruments for close work.

Effect of Inclined Sight on Stadia Readings.—The previous discussion is based on a level line of sight. It should be borne in mind that the stadia distance as previously discussed refers to the distance along the line of sight when the rod is perpendicular to the line of sight.

In case the line of sight is inclined, the rod reading must be corrected to a true rod reading perpendicular to the inclined

line of sight and the distance along the inclined line of sight mus be corrected to the true horizontal distance.

Rod interval × cos A (angle of inclination) = corrected ro interval.

(Corrected rod interval in feet × actual distance value per foo as determined by test × cos angle A) + (the constant C × co angle A) = corrected horizontal distance.

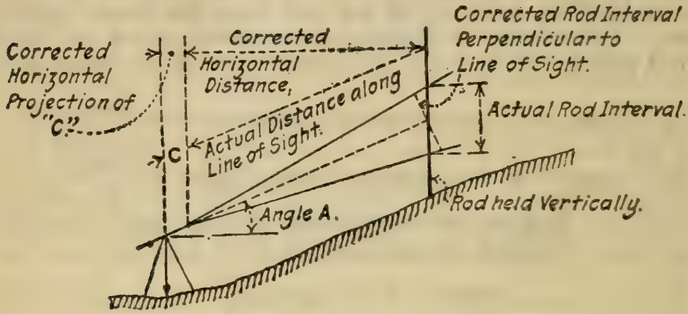


FIG. 303.

(Corrected rod interval in feet × actual distance per foot of ro interval as determined by test × sin of angle A) plus (constant × sin angle A) = corrected vertical distance.

All standard stadia reduction tables and diagrams similar t Table 137 (p. 844), are based on 100′ of distance for 1.0 of ro interval plus the constant of the instrument.

If much stadia work is to be done all instrument makers wi set fixed stadia wires guaranteed to measure 100′ distance per 1

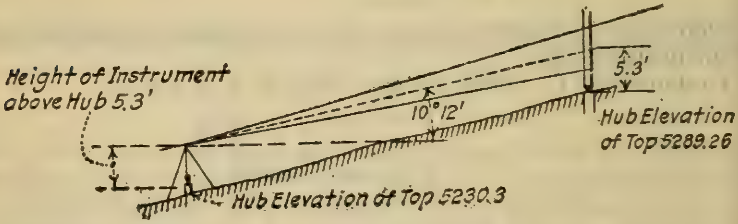


FIG. 304.

of rod interval for the distance from the apex of the optical angl and such wires are generally sufficiently close to this standard s that for all practical survey work on which stadia methods ar desirable no correction for rod interval need be applied.

The following example of reduction of stadia reading for caref line work will show the method.

Case 1.—Where the stadia wires are guaranteed to read 10 distance per foot of rod interval and the constant C = 1.25′.

Procedure.—Measure the height of the center of the telescope axis at the standards above the top of the transit hub; this is called the height of instrument. Assume this, for example, to be 5.3′.

To get the vertical angle to the next hub sight on the rod with the middle horizontal wire set on 5.3′ on the rod held on the foresight hub and read the vertical angle, say $+10° 13'$; level the telescope by the large telescope bubble and record the index error, say $+0° 01'$; the correct vertical angle is then $+10° 12'$.

To get the rod interval reading corresponding to the vertical angle of $+10° 12'$, sight on the rod with the middle horizontal wire on 5.3′: then shift the vertical line of sight so that the lower stadia wire is exactly on one of the main rod divisions and read the rod interval between the two stadia wires. Say in this case 3.37 or 337′ distance. Look in Table 137 (p. 844), which gives for a vertical angle of 10° 12′ the correct horizontal and vertical distance per 100′ of stadia reading as horizontal distance 96.86′; vertical difference in elevation 17.43′. The total horizontal distance for the stadia reading of 337′ is therefore $(337 \times 96.86 = 326.42) + (\text{constant } C \times \cos 10° 12')$ given at bottom of page in table as 1.23) = 327.65 *total horizontal distance.*

The vertical difference in elevation is $(337 \times 17.43' = 58.74') + ((\text{constant } C \times \sin 10° 12')$ given at bottom of page in Table 137 as 0.22) = 58.96′ total difference in elevation. The elevation of the new hub is therefore $5230.3 + 58.96 = 5289.26$.

Case 2.—Where a stadia interval must be corrected for poor wire interval.

Suppose the instrument used measures 100.3′ for each foot on the rod and the rod reading for a vertical angle of 10° 12′ is 3.36′. The correct stadia distance is found by multiplying $3.36' \times 100.3 = 337'$ in distance. Then proceed as in Case 1.

Stadia Rods.—Stadia rods can be divided in innumerable ways and it makes little difference what symbols are used so long as they are clear and distinct. The principle of bisection for the smallest readings is a good system. The face of the rods should be wider than the ordinary level rod; a width of 2½ to 3″ is about right. They should have a very brilliant white background and jet-black face markings with large numbers for the even feet mark-*the tenths should not be numbered.*

The practice of special graduations to fit the wire interval of the instrument is not desirable, particularly in rough country where rods are often broken.

A standard 1.0′ division is safer, as any standard rod can then be used.

The following system of face markings has been used by the author and is given merely as an example in case the reader has no preference of his own.

The rods should be as light as possible with a back brace to prevent warping and provide hand holes. A length of 10′ is ample for all practical purposes.

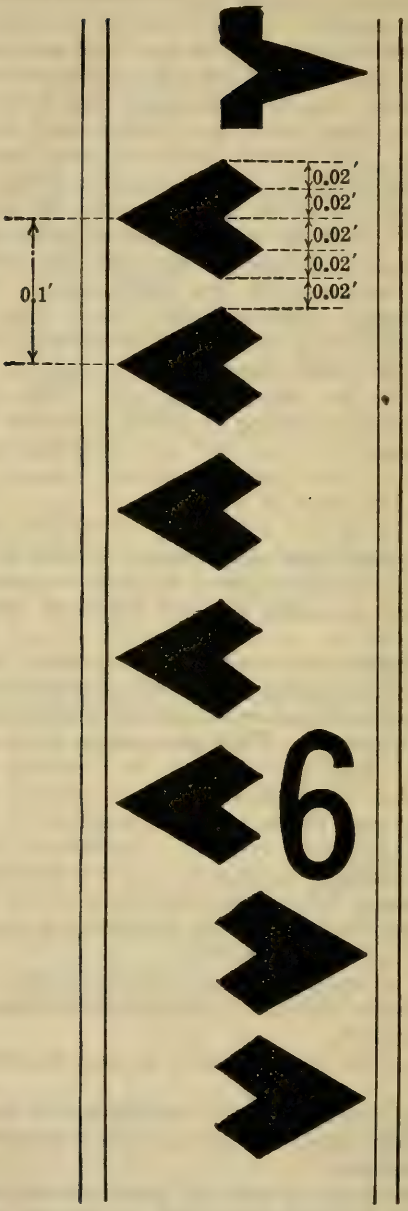
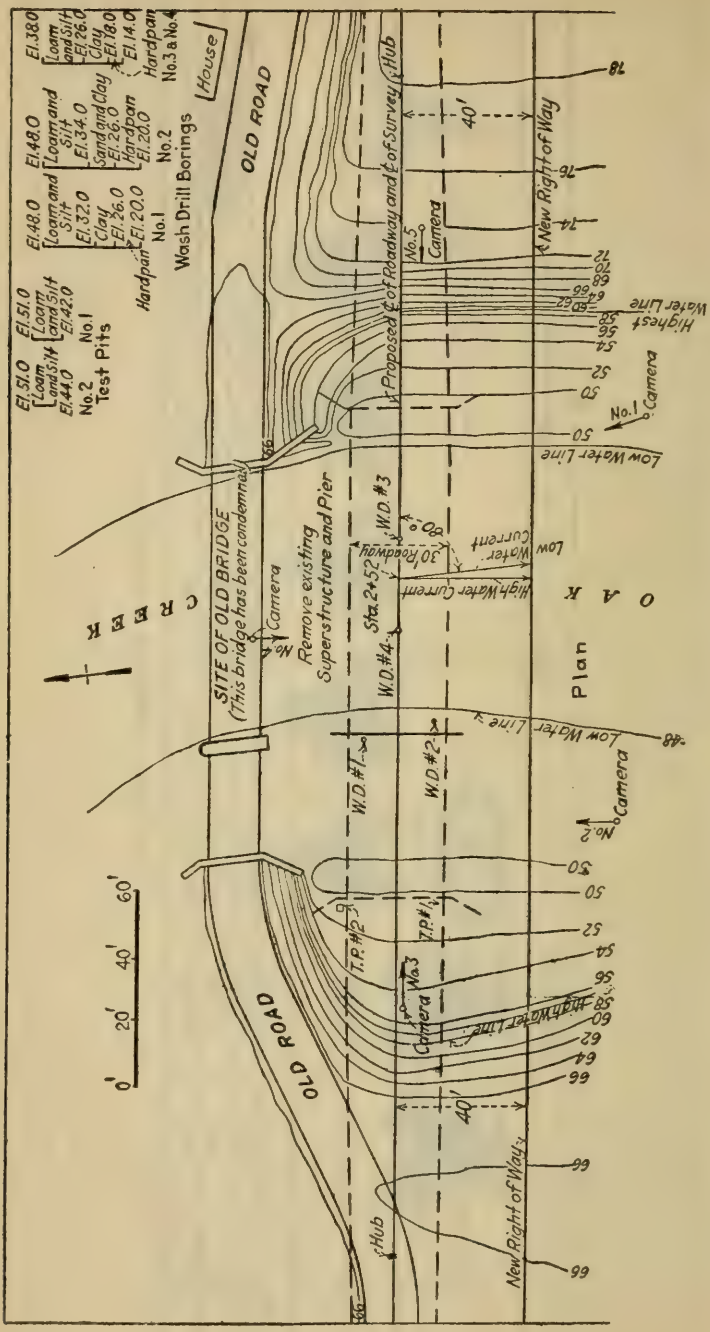


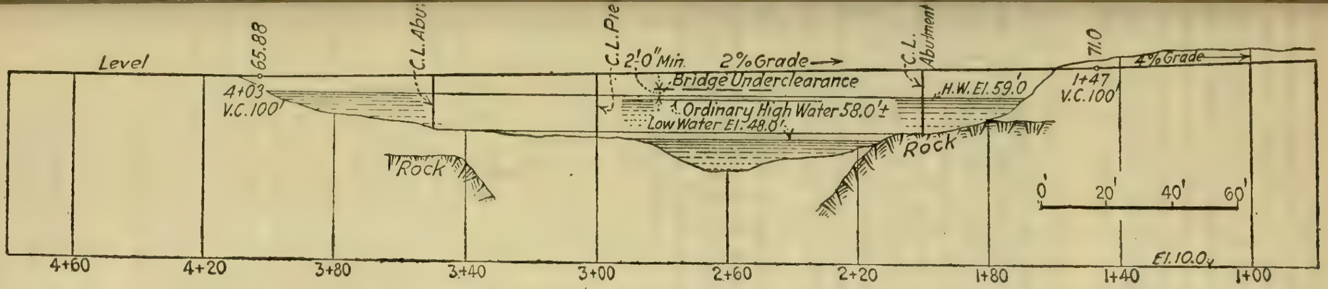
FIG. 305.—Stadia rod.

Left Page					*Right Page*			
⩚ *at Hub B.* Elevation Hub B-725.7 Height of instrument above hub 4.9′. All vertical angles taken at rod readings of 4.9 unless otherwise noted. Back sight on Hub A. (F + C = 1.0′.)					Nearest 0.1 for hub shots Nearest 1.0 for ordinary shots			
Shot	Distance	Horizontal angle	Vertical angle	Special vertical angle rod readings	Corrected horizontal distance	Difference in elevation	Elevation of shot	Location of shot
Hub A	247′	0° 00′	−2° 10′	...	247.6	− 9.4	716.3	
1	155	10° 20′	−1° 16′	...	156	− 3.4	722.3	North Bank Creek
2	140	10° 30′	−3° 44′	...	140	− 9.2	716.5	Waters edge
3	370	276° 35′	+6° 10′	6.9	366	+37.6	763.3	N. E. cor. house

FIG. 305*A*.—Sample Stadia Notes.



El. 51.0 Loam and Silt El. 44.0 No. 2
El. 51.0 Loam and Silt El. 42.0 No. 1
Test Pits
El. 48.0 Loam and Silt El. 32.0 Clay El. 26.0 Hardpan El. 20.0 No. 1
El. 48.0 Loam and Silt El. 34.0 Sand and Clay El. 26.0 Hardpan El. 20.0 No. 2
El. 38.0 Loam and Silt El. 26.0 Clay El. 18.0 El. 14.0 Hardpan No. 3 & No. 4
Wash Drill Borings
House
OLD ROAD
CREEK
SITE OF OLD BRIDGE
(This bridge has been condemned)
Remove existing Superstructure and Pier
Proposed ℄ of Roadway and ℄ of Survey
Hub
New Right of Way
40'
30' Roadway
Sta. 2+52
W.D. #1
W.D. #2
W.D. #3
W.D. #4
T.P. #1
T.P. #2
High Water Current
Low Water Current
Low Water Line
Highest Water Line
High Water Line
Camera No. 1
Camera No. 2
Camera No. 3
Camera No. 4
Camera No. 5
OAK
Plan
0' 20' 40' 60'



Cross Section

FIG. 305*B*.—Typical bridge layout plan for design purposes.

Clear waterway at existing bridge = 2060 square feet.
Clear waterway at other bridges over stream. 2100 *at bridge* 1 *mile north of present bridge*
Is waterway at existing bridge sufficient or too large? *Sufficient*
Is stream ever dry? *No.* Elev. of permanent ground water: El. 46.0 ±
Velocity of current. *Sluggish most of the time, very rapid during spring floods.*
Does erosion occur? *No.* Best way of preventing erosion——
Does stream carry light, medium or heavy drift? *Light drift.*
What clearance above highest water? 2′ *minimum is O.K.*
Foundation data. *See test pits and wash drill borings*
Should piles be used? *Yes, for pier only.*
Recommend spans: 1′–50′ *span and* 1′–100′ *span*
Material in stream banks. *Rock east side, clay in west bank.*
Proposed type and width of pavement = *Concrete,* 18′ *width.*
Width of embankment = 28 *feet*
Will side walls be required? *No.*
Should provisions be made for water pipes, etc.? *No.*
Does stream come under jurisdiction of war dept. *No.*
Can a portion of existing abut. be used for new bridge? *No.*
Type of foundation under existing bridge. *Abutment on rock and center pier on timber crib*
Estimate safe load on foundation. 10 *tons per square foot about for abutments*
Slope of embankment on approaches. 1 *on* 1½
If it is proposed to use a portion of existing bridge abutments for new bridge, the existing abutments should be shown to a scale of 1″ = 10′

Cross section of proposed bridge and approaches Scale: 1″ = 20′–0″

Plan and profile of proposed bridge site for bridge over Oak Creek at Sta. 2 + 52 on Ada-Kent Co. Highway, Apple County, Dec. 18, 1925.

Bridge Surveys.—The base line for the bridge survey should be a very carefully measured line, correct to within 1" for the span proper and with the hubs well referenced. Direct steel-tape measurements are preferred, but if this is not feasible and triangulation is required two independent systems of triangulation should be usedas checks on each other. Steel tapes should be certified standard and distances should be corrected for temperature. The topography along the stream and adjacent to the bridge site can generally be most easily and properly located by careful stadia survey methods.

Enough data should be obtained to permit the preparation of a plan containing all the information shown in Fig. 305*B*. This covers all data in regard to the location condition and size of the existing structure; stream channel for a sufficient distance above and below the proposed bridge site to cover all possible channel improvements and to permit a reasonable bridge location layout to be made; foundation elevations and character of soil; high- and low-water elevations; all adjacent topographic features and property owners; waterway area of adjacent bridges and general type of opening which has served satisfactorily on the stream considering ice and débris jams.

Ordinary survey methods and notes previously described will serve for this class of survey. It is desirable to record all stadia horizontal angles on the basis of azimuth angles (0° to 360°) measured to the right from the north point or back site. Permanent benches must be established correct in elevation to 0.01 '.

CHAPTER XIV

OFFICE PRACTICE

Introduction.—Effective design is based on the principle of the preparation of alternate comparative designs in order to pick the most suitable or economical solution (see design report, pp. 770 and 1095). By the use of this method of alternate designs a good engineer will reduce construction costs at least 10 to 20% below those obtained by the usual stereotyped application of standards with little thought to the local problem. First-class office design costs from $150 to $400 per mile and any effort to cut cost below the amount required for thorough design is poor economy, as indicated by experience of over 20 years.

Estimates of quantities should be liberal in order to avoid the necessity of supplementary agreements during the progress of construction, but in order not to mislead the contractor in making his bid, it is necessary for the estimate to show the probable minimum amount for each item with a statement of the amount allowed for contingencies. Cost estimates should be fairly liberal. They should never be below an amount which will insure a reasonable profit with ordinarily favorable luck and foresight. This matter of cost is important, as a poor price is almost certain to result in inferior work.

The discussion of office practice will be handled in the same general manner as the discussion of the survey, namely, under the general divisions of:

a. The improvement of existing roads.

b. The location of new pioneer roads.

It is impossible in a book of this character and size of page to illustrate exactly the detail methods of design which carry out the principles of economy discussed in Part I, but an effort has been made to give an idea of the practical methods by restricted examples and rather full explanations of drafting-room procedure. The tabular data in connection with design and estimating quantities have been found from experience to be very useful.

THE IMPROVEMENT OF EXISTING ROADS

Office practice includes:

1. Mapping the preliminary surveys.
2. Designing the improvement.
3. Estimating quantities and cost.
4. Finished contract plans.
5. Records and record maps.

1. Mapping the Preliminary Survey

The mapping of the preliminary survey serves as a base from which the design of the new work, and the quantities necessary thereto, can be built up. It consists of three views of the road: the plan, showing the topographic features; the profile, showing the longitudinal differences of elevation, and the cross-sections, showing the constantly changing transverse shape.

The scales in general use are as follows:

TABLE 148

Plan	Profile	Cross-sections
1″ = 100′	1″ = 100′ horizontal 1″ = 10′ vertical	1″ = 10′
1″ = 50′	1″ = 50′ horizontal 1″ = 10′ vertical	1″ = 5′ or 1″ = 4′
1″ = 20′	1″ = 20′ horizontal 1″ = 5′ vertical	1″ = 5′ or 1″ = 4′
1″ = 10′	1″ = 10′ horizontal 1″ = 10′ vertical	1″ = 2′

NOTE.—Distorted profile scales have a strong tendency to increase grading costs, as it is a matter of common experience that if a grade line is designed by the same man for the same road using a distorted profile in one case and a natural scale profile in the other case, the quantities resulting from the distorted profile are much in excess of the natural scales. Some distortion is necessary but the designer should ride over the road and from visual inspection determine what rolls in the natural grade can be properly retained and what sharp grade changes must be reduced. With a little experience of this kind he can coordinate actually good riding profiles with the distorted profile on which he is working and he will not needlessly cut and fill smal changes in the natural grades (see also pp. 109 and 963).

For court cases it is not permissible to use distorted scales, as the average judge or jury do not understand them and are misled by their use.

The 100′ scale is too small for convenience in design, and earthwork quantities figured from cross-sections plotted 1″ to 10′ are not reliable. For work on ordinary country roads, the 50′ scale is generally adopted, using cross-sections plotted 1″ to 5′ or 1″ to 4′; this scale is satisfactory for laying the grade line and computing the earthwork.

The larger scales of 1″ = 20′ or 1″ = 10′ are useful in village work where a large amount of detail must be shown.

Plotting the Center Line.—The survey center line can be plotted by deflection angles at the transit points, using a table of natural tangents, a vernier protractor or an ordinary paper protractor graduated to 15′.

Where the center line has been well located in the field and there seems to be no necessity for a paper relocation, no great care need be taken in plotting the deflection angles, as in such a case the map serves more as a picture of the topographic features than as a basis for alignment.

Where a random line has been run in the field and some shifting of the center line is necessary, both angles and distances must be accurately plotted. If any extensive change of alignment is made, the new deflections and distances should be checked by figuring the difference of latitude and longitude for both the survey line and the office line between the points of equality.

Where the consideration of sight distance (see p. 114) governs Table 149 will be of service.

TABLE 149

Table 149 gives the approximate distance that an automobile driver can see an approaching car, assuming that he is driving in the center of the road and that the approaching car is also in the center. Two distances are given for each curve, the first assuming that the line of sight is six feet from the ground, which is about right if the curve is on a straight grade, and makes the line of sight tangent to the cut slope of 1 on 1½, 19 feet off center for the narrow section shown in Fig. 15, page 115, and, second, assuming that the line of sight is close to the ground, as occurs on rounding the top of a hill, in which case the line of sight will be tangent to the side slope at, approximately, 11′ off center.

Degree of Curvature	Radius of Curve Feet	Sight Distance Case One. Feet	Sight Distance Case Two. Feet
5	1146.0	400	310
6	955.0	375	290
7	818.6	350	270
8	716.3	330	250
9	636.6	310	235
10	573.0	295	220
12	477.5	270	200
14	409.3	245	185
16	358.1	230	175
18	318.3	220	165
20	286.5	210	160
30	191.0	170	130
40	143.2	145	110
50	114.6	130	100

For convenience in plotting the topography, the 100′ survey stations are plainly marked.

The most common mistakes in plotting the map are made by reversing the deflection, as right instead of left and *vice versa*, or in adding or omitting 100′ in scaling long-tangent distances.

The work should be checked for mistakes of this nature.

All curve data are marked plainly on the map near the P.I. and show:

The deflection angle Δ
The degree of curve D
The radius of curve R
The tangent length T
The length of curve L
The station of the P.I.
The station of the P.C.
The station of the P.T.

If the curves have been figured in the office and have not been run in the field it is good practice to scale the offsets from the tangent to the curve and mark them on the map.

These offsets from the center line as run are then transferred to the cross-sections and the profile plotted from center-line elevations on the cross-sections.

Plotting the Topography.—If the topography has been recorded by a system of right-angle offsets, as suggested and illustrated on page 837, it can be easily and quickly plotted by using the transparent scale shown here.

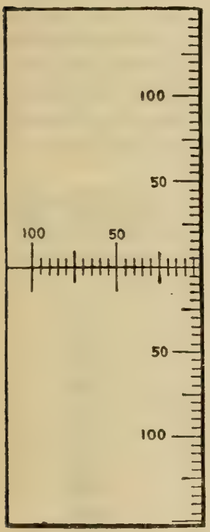


Fig. 306.—Convenient transparent scale for plotting topography.

This scale gives the plus distance along the survey base line, or center line, and the offset distance from the line in one operation.

As a general rule, the plotting of the topography need not be checked.

Level Computations.—The survey computations of the bench levels are checked and a list of bench elevations prepared; these elevations are used in cross-section level notes and from them the notes are computed between benches. As each bench is reached these notes are corrected to agree with the elevation adopted for that bench and then carried forward on the corrected basis. The allowable error for cross-section levels, as mentioned in the chapter on surveys, is less than 0.1′. The correction of the levels at each bench prevents any cumulative error and makes the elevations of the cross-section shots agree with the adopted bench elevations with an error of less than 0.1′. This is as close a the readings can be plotted and as close as they can be read in the field.

The computation of the bench levels and the adjustment of the cross-section notes should be checked by a competent man. The most common mistake in figuring the cross-section readings is to use the wrong height of instrument for a section. Such a mistake cannot be detected in plotting the sections, but is generally discovered when the profile is plotted.

In checking the notes particular care should be taken on this one point.

Plotting the Cross-sections.—The cross-sections must be *very carefully* plotted, as the reliability of the earthwork computation depends largely on their accuracy.

The cross-section paper used should be exact in the divisions and should be printed or engraved from plates.

Ruled paper is inaccurate.

The plotting is checked by reliable men. Reading the shots back from the plotted cross-section is preferable to reading them from the book. The elevations of the center line and of the ditch line are written over the section. The station number or plus of each section is written on the right margin. The fact that the section has been graveled within the traveled way, that stone has been spread to a certain thickness, or any other fact that would influence the designer when laying a grade line, is noted on the section (see Fig. 307).

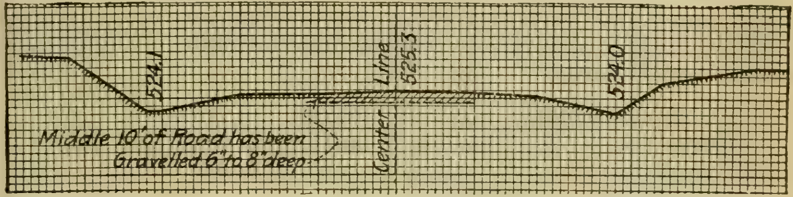


FIG. 307.

It is common practice to allow the inexperienced men to plot and check the cross-sections. This is a mistake. This part of mapping is the most important of the preliminary plans, and the work should be plotted and checked so that the points are correct to the nearest 0.1′ in elevation.

These points are then connected with a fine ink line.

Plotting the Profile.—The profile is plotted from the center-line elevations given in the cross-section notes unless the proposed center line does not coincide with the survey center line, in which case the elevations of the proposed line are projected from the previously plotted cross-sections.

It is not necessary to spend so much time for accuracy in plotting as on the sections, as the profile only serves as a guide in laying the grade line and no quantities depend upon its correctness. An error of 0.2′ is allowable.

The elevation of each plotted center-line point is recorded with its stationing (see Fig. 322, p. 1106).

The profile should show all existing culverts and bridges with elevations of both present roadway, top and bottom of existing waterway opening, and elevations of high water. It should show all rails of grade crossings, the location of houses and barns effecting cuts and fills, and all crossroads or streets. Supplementary profiles of crossroads should also be shown to insure good intersection designs for both grade and drainage.

2. Designing the Improvement

The completion of the profile finishes the preliminary mapping. The first operations of the office design are as follows:

A. Selection of grading section.
B. Depth, width, and crown of pavement.
C. Final alignment.
D. Laying the grade line.

These four points are so dependent on each other that they cannot be separated, as they all vary from point to point on the road, depending on soil, traffic, grade, special topographic features, bridges, etc.

The most experienced man available should do this part of the work. He should be thoroughly familiar with the road from field inspection, and in designing he should follow the general principles laid down in Part I, in the chapters on Grades, Alignment, Sections, Pavements, and Reconstruction. For convenience the most-used data from these chapters are repeated at this point in tabular and diagrammatic form.

Table 150 (p. 949), maximum grades.
Table 151 (p. 950), maximum curvature.
Figure 308 (p. 951), typical grading sections.
Table 152 (p. 950), typical crowns.
Figure 309 (p. 956), typical superelevations on curves.
Table 152*C* (p. 958), typical pavement widths.
Table 153 (p. 959), depths of flexible pavements.
Table 154 (p. 960), depths of concrete foundations.
Table 155 (p. 962), limiting gradients, different pavements.
Table 156 (p. 962), special qualifications, different pavements.

TABLE 150.—RECOMMENDED PRACTICE MAXIMUM GRADES

Recommended Practice, Maximum Grade Design.—From the standpoints of horse traffic, single unit motor traffic or trucks with one trailer, safe footing, and economy of construction and maintenance, the following recommended rates of maximum grades will give moderately good satisfaction. In unusual cases the possibility of the extensive use of long trailer trains would tend to reduce these recommended rates, but the author wishes to emphasize the opinion that very few roads need be designed at this time primarily for long trailer trains. The following rates are satisfactory for the ordinary motor equipment used by the great majority of road users and additional expenditure would not be warranted for the benefit of a few men. *For the effect of dangerous alignment on maximum grade see page* 118. *For Effect of grade on motor operation cost see pages* 12 *and* 96.

Main Commercial Roads in Flat Country.—Long 2 % ruling grades are desirable but do not justify much additional construction cost. Any long ruling grade up to 5 % will probably be satisfactory. Short 6 % are not inconsistent. A large volume of hauling by trailer trains might warrant reductions below usual practice provided the interests operating such haulage paid the increased cost of construction.

Main Commercial Roads in Hilly Country (Well-settled Districts).—Long 5 % ruling grades are desirable and justify considerable expenditure provided they do not increase the total distance; 7 % grades are probably justified to prevent increase in distance for a fixed rise. Long 6 % grades are fairly satisfactory but as a rule if 5 % cannot be reasonably obtained it is just as well to jump to 7 %. Short 7 or 8 % grades are not inconsistent in connection with long 5 and 6 % grades provided the element of safe team footing is considered.

Main Roads, Pioneer Districts.—Long 5 % grades are very desirable provided they do not increase the total distance, particularly if the road is a natural soil road and considerable horse traffic prevails. Any long grade up to 7 % is fairly satisfactory. Short 7 and 10 % grades are not inconsistent except for trailer trains. Grades higher than 7 % are not, however, in much favor on account of danger and high maintenance cost.

Side Agricultural Roads or Unimportant Pioneer Roads.—Any long grade up to 7 % is satisfactory. Short 10 % grades are consistent in connection with a 7 % ruling provided the element of safe footing is considered. Grades steeper than 7 %, however, have a high maintenance cost.

Scenic Roads.—Long 6 % grades are convenient on account of preventing gear shifts; 10 % is not unreasonable for such roads except that on a 10 % grade, the alignment should be easy, see page 118, and the maintenance cost is high.

Compensation of Steep Grades.—On sharp curves maximum grades must be reduced (see page 118).

Recommended Alignment Practice.—The following summary agrees with general current practice and can often be used without raising the cost beyond the bounds of reason. A summary of this nature is of course of only general value. Each case must be worked out on its own merits. Broad generalizations of detail requirements are dangerous if used indiscriminately.

Table 151.—Recommended Alignment Practice

Main Commercial Roads (Well-settled Districts).	
Minimum sight distance	300 to 400′
Minimum radius of curvature at right-angle turns on level outside of villages where sight distance does not control	250 to 400′
Minimum radius of curvature on steep grades or at the foot of such grades depending on the central angle where the sight distance is not the controlling factor	600 to 800′
Ordinary Agricultural Roads. (Local Service.)	
Minimum sight distance	200 to 250′
Minimum radius of curvature at right-angle turns on level outside of villages	100 to 200′
Minimum radius of curvature on steep grades where sight distance does not govern	400 to 600′
Mountain Roads.	
No limitations on sight distance.	
Warning signs used where necessary.	
Minimum radius on steep grades	100′

Minimum radius in extremely rough country 40 ft. Grades not to exceed 3 % for a 40-ft. radius and not to exceed 4 % for an 80-ft. radius. Any grade up to 8 % on a 100-ft. radius, although it is desirable not to exceed 5 % on a 100-ft. radius curve with a large central angle.

Note.—There is no more object in long perfectly straight tangents than there is in long uniform rates of grade. In a great many cases small angles in long stretches of comparatively straight road are eliminated by the adoption of a long single tangent resulting in a noticeable increase in cost and often in the loss of retention of the existing solid roadbed. In a great many cases the only value of such changes seems to be the pleasure derived by the office engineer in laying his straightedge on the plan and drawing a nice long straight line.

Table 152A.—Rural Highways—Typical Normal Pavement Crowns

Parabolic or Circular arc suitable			
Kind of pavement	Average maximum crown slope, inches per foot	Average minimum crown slope, inches per foot	Average recommended crown slope, inches per foot
Earth roads	1	1/2	5/8
Sand-clay roads	3/4	1/2	5/8
Gravel roads	3/4	1/2	1/2
Single-track water-bound macadam	3/4	5/8	5/8
Double-track water-bound macadam	1/2	3/8	3/8
Double-track bituminous macadam	3/8	5/16	5/16
Double-track bituminous concrete	3/8	1/4	1/4
Double-track cement concrete	1/4	1/8 [1]	3/16
Double-track brick	3/8	5/16	5/16
Double-track asphalt block	3/8	1/4	1/4
Double-track stone block	1/2	3/8	3/8

[1] For the 1/8″ crown use a straight-line crown slope.

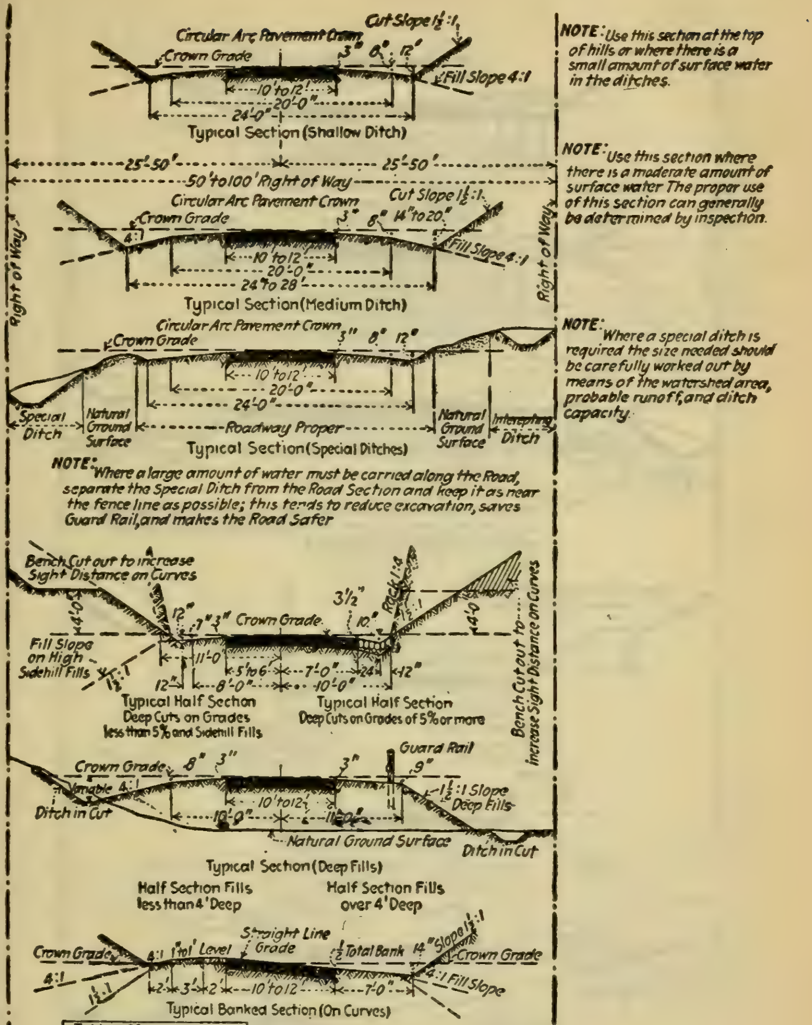


Table of Banked Crowns

Radius of Road C. L.	Rate of Banked Crown
50' to 200'	3/4 in to 1 foot
200' to 500'	3/4 " " 1 "
500' to 800'	3/4 " " 1 "
800' to 1000'	1/2 " " 1 "

NOTE: Single Track Macadam Roads do not have enough Traffic to warrant widening the Pavement at Curves

FIG. 308A.—Single track macadam or gravel roads (suitable for roads carrying up to about 300 vehicles per day).

NOTE.—For discussion of sections see Chapter III.

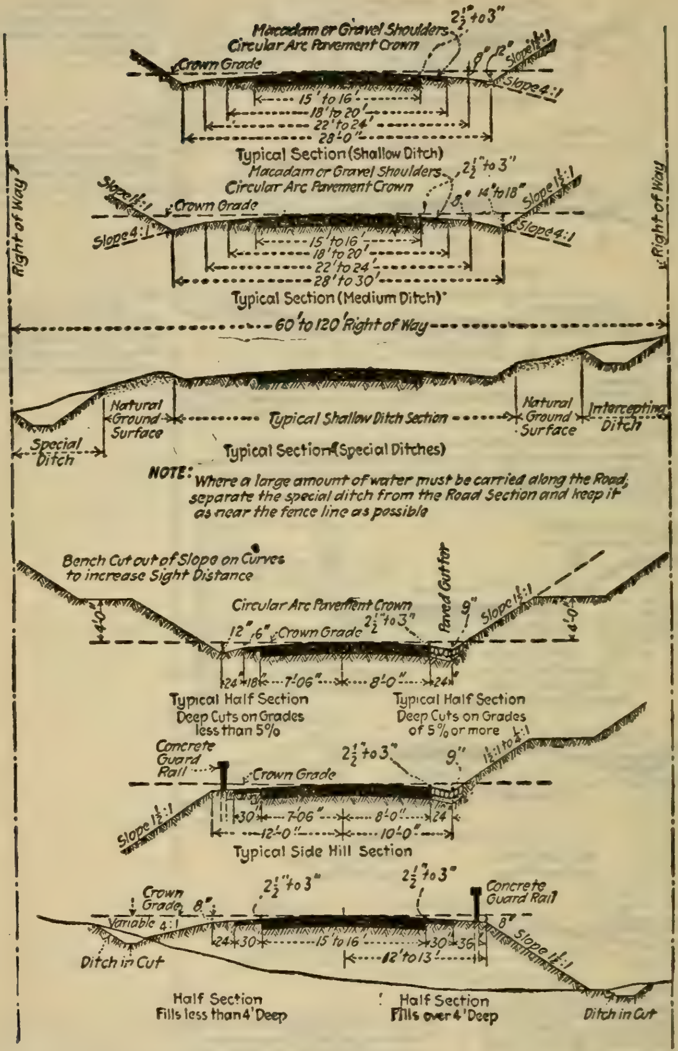
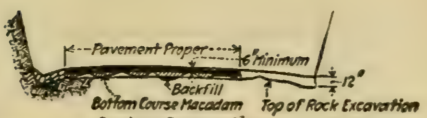


FIG. 308*B*.—Double track macadam roads. Suitable for local service or secondary State Roads carrying from 300 to 2000 vehicles per day (12 hour count in summer).

NOTE.—For roads carrying over 1500 vehicles daily use 7 ft. shoulder to permit parking off the pavement.

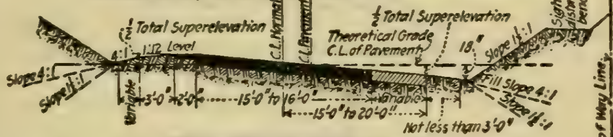


Typical Rock Section

NOTES:

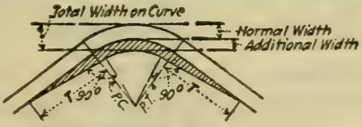
Rock excavation will be paid for to an elevation 12 inches below the surface of the finished road and no rock excavation will be paid for below this elevation or outside of the neat side slopes shown on the plans.

No part of the solid rock shall be closer than 6 inches to the top of the finished section. All depressions under the pavement proper lower than the bottom of the bottom course of the pavement shall be backfilled with stone chips, filled with sand or gravel and rolled or tamped until firm and hard. This backfill is included in the price bid for rock excavation.



Typical Section (Sharp Curves)

Table of Rate of Superelevation	
Radius of Road Center Line in Feet	Rate of Superelevation
50 - 200	3/4 in to 1 foot
200 - 500	3/4 " " 1 "
500 - 800	3/4 " " 1 "
800 - 1000	1/2 " " 1 "



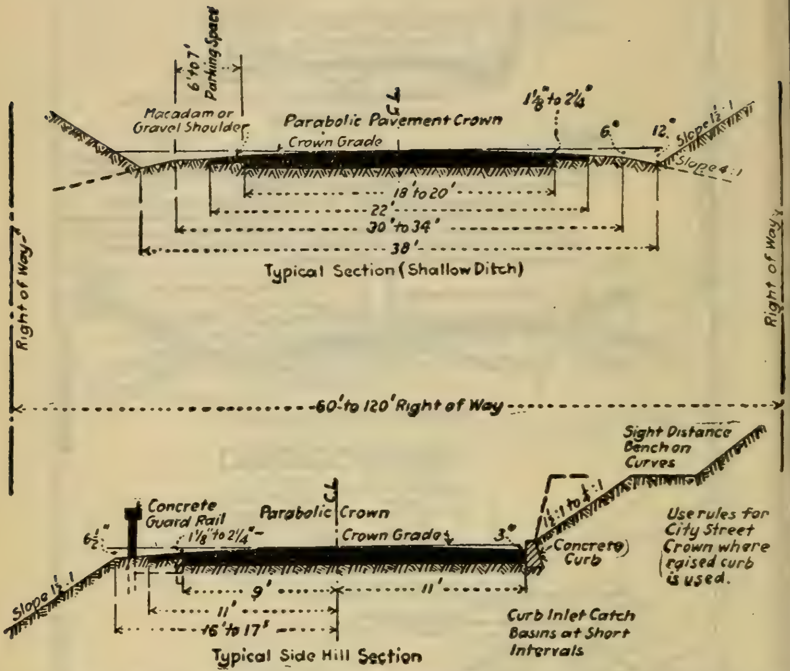
Pavement Widening Layout

Table of Pavement Widening		
Radius of Road Center Line in Feet	Total Width Pavement on Curves	"T" Feet
50 Feet	29 Feet	100
75 "	25 "	100
100 "	23 "	100
200 "	21 "	90
300 "	20 "	80
400 "	20 "	80
500 "	19 "	70
600 "	18 "	50

NOTE: Use normal Pavement Width on Curves having a radius of more than 600 feet

Table of Recommended Total-Depth of Macadam Pavements on Different Soils			
Pavement in Cut or Fill	Soils		
	Sand or Gravel	Loam	Heavy Clay or Quicksand
In Cut	8"	9" to 12"	15" to 24"
On Fills less than 1 ft deep	8"	9" to 12"	15" to 24"
" " 1 ft. to 3 ft "	8"	9"	12" to 15"
" " over 3 ft. "	8"	8"	9"

FIG. 308*B*.—Double track macadam roads.



TYPICAL MEDIUM DITCH SECTION " SPECIAL " " " FILL SECTION " BANKED "	Similar to Fig. 308 except that the Overall Width dimensions are 6′ to 8′ ft. greater than given in Fig. 308

ROCK EXCAVATION: Method of Payment similar to Fig. 308*A* except that none of the Solid Rock shall project above the bottom of the Pavement Base

NOTE: For thickness of Pavements and Design of Pavement Base and Surfacing See Volume 2

FIG. 308*C*.—Special sections rigid pavement roads (roads carrying over 2000 vehicles per day).

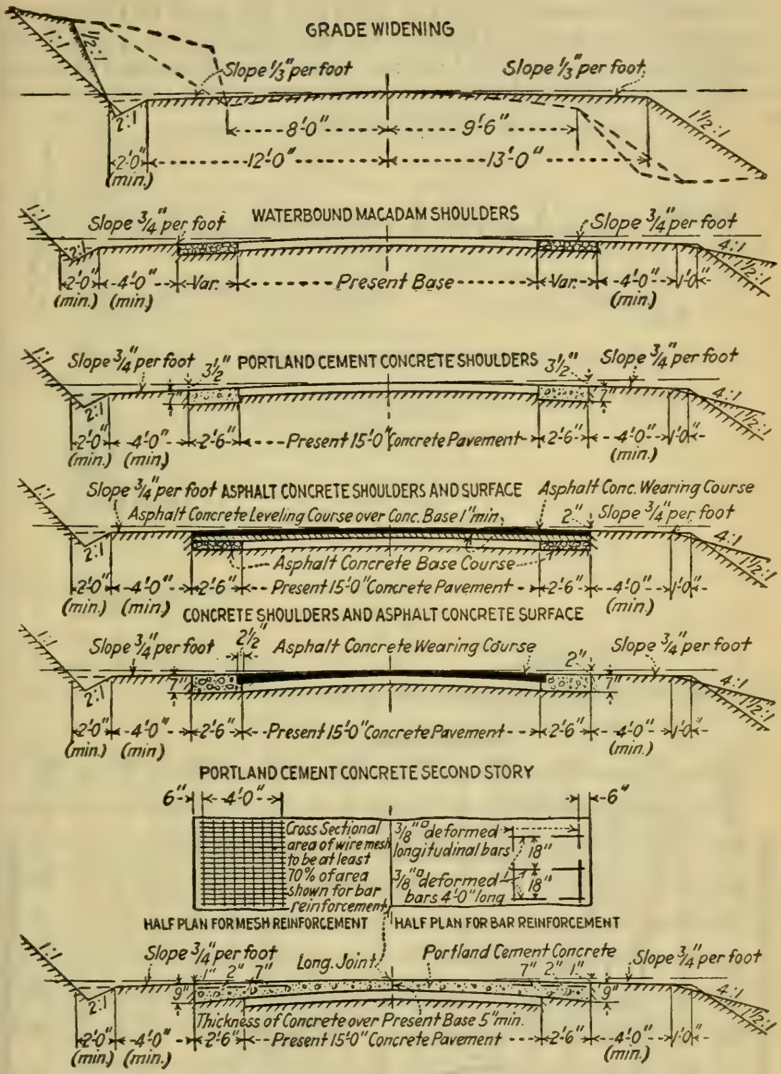
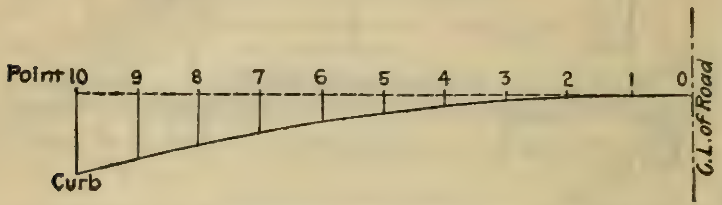


FIG. 308*D*.—Reconstruction sections, state of California 1926. Widening and thickening old state roads.

NOTE.—See Chapter VIII for discussion of reconstruction design.

Parabolic Crowns for Pavements.—It is often convenient to have the following data on parabolic crown ordinates in making templets for pavement work.

Divide the distance from the center of the road to the curb or edging into ten equal parts and call the total crown 1.0; the distance down to the surface of the pavement from the crown elevation at each of these ten points expressed in terms of the total crown will be



Parabolic crown ordinates.

Center of road, point No.	0	0.00
	1	0.01
	2	0.04
	3	0.09
	4	0.16
	5	0.25
	6	0.36
	7	0.49
	8	0.64
	9	0.81
Curb point	10	1.00

For area Parabolic Segments see page 1576.

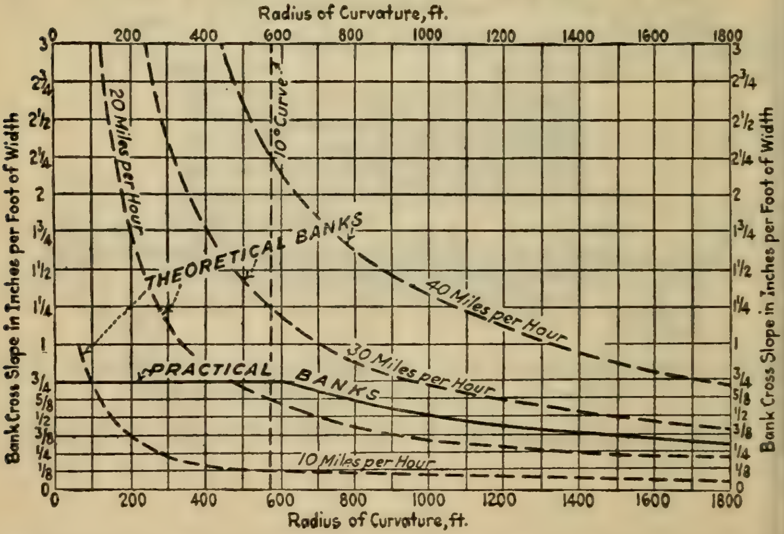
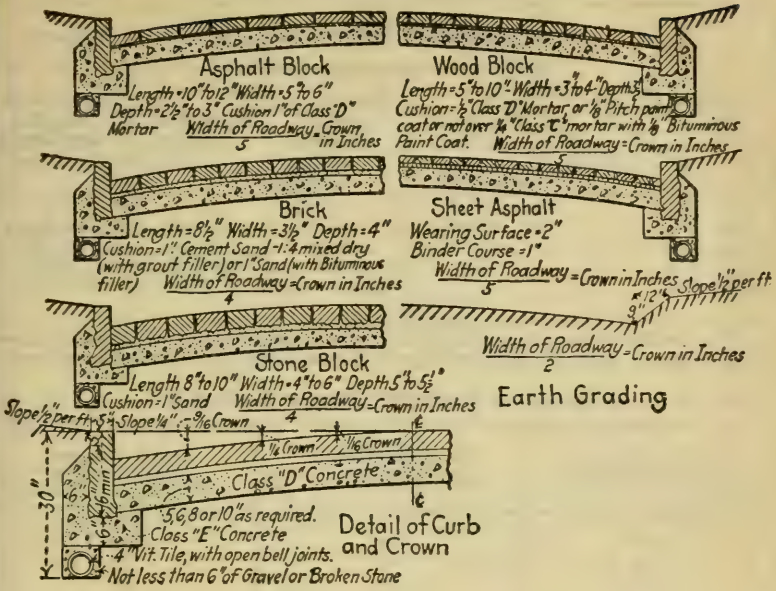
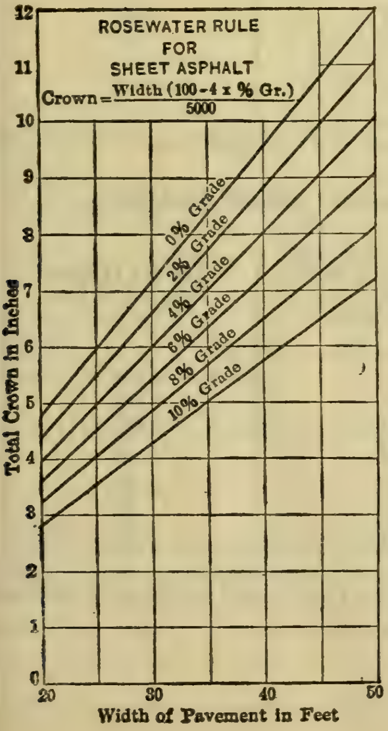


FIG. 309.—Graph of theoretical and practical bank slopes on curves

NOTE.—For discussion of superelevation see page 124.

TABLE 152*B*.—STREET CROWNS





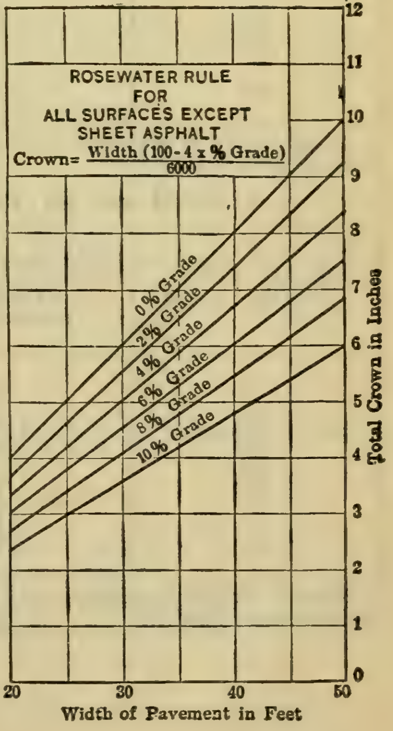


TABLE 152C.—NORMAL PAVEMENT WIDTHS (IN FEET)

Class of road	Rigid pavements		Macadam or gravel	
	Pavement proper	Out-to-out width armored shoulders	Pavement proper	Out-to-out width armored shoulders
Class I[1]	18–20	22–24	18–20	22–24
Class II	17–18	20–22	15–16	20–22
Class III	16	16	12–16	16
Class IV	.....	.....	8–12	

[1] For traffic of over 6,000 daily (10-hour count in summer) increase pavement width to 27 or 36′, see also page 28 for capacity 3 and 4 lane pavements.

CLASS I TRAFFIC (SHARP CURVES)

Radius of road center line in feet	Total pavement width in feet	Length tangent run-off in feet
100	25	100
150	24	90
200	23	90
300	22	80
400	22	80
500	21	70
600	21	70

NOTE.—Normal pavement widths of 18 to 20′ used on all curves having a radius greater than 1000′.

CLASS II AND III TRAFFIC (SHARP CURVES)

Radius of road center line, in feet	Total pavement width on curves for a double-track road (local service) in feet	Length tangent run-off in feet
50	29	100
75	25	100
100	23	100
150	22	90
200	21	90
300	20	80
400	20	80
500	19	70
600	18	50

NOTE.—Normal pavement width (15 to 18′) used on all curves having a radius greater than 800′.

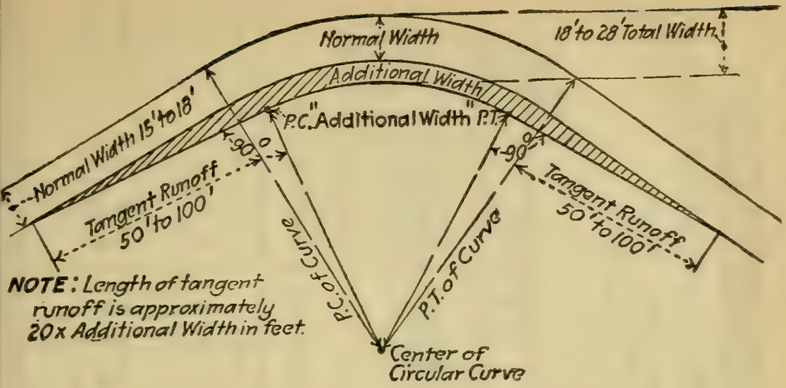


FIG. 310.—(Table 152C.)

TABLE 153.—RECOMMENDED TOTAL DEPTHS OF FLEXIBLE PAVEMENTS IN LOCALITIES SUBJECT TO SEVERE WINTERS (IN INCHES)

Soil	Location of road: In cuts or on shallow fills less than 1′ deep	On intermediate fills 1 to 3′ deep	On high fills over 3′ deep
Class I traffic (over 2000 vehicles daily, 10-hr. count in summer; (M. macadam not usually economical on Class I roads)			
Coarse sand and fine gravel	9–10	9–10	9
Loams	10–14	10–12	10
Ordinary clays	15–21	12–16	11
Heavy clays and fine sands	22–30	14–18	13
Class II traffic (800 to 2000 vehicles daily, 10-hr. count in summer			
Sand and gravel	8– 9	8– 9	8
Loams	9–12	9–11	9
Ordinary clays	12–18	11–15	10
Heavy clays and fine sands	18–28	13–16	12
Class III traffic (300 to 800 vehicles daily, 10-hr. count in summer)			
Sand and gravel	7– 8	7– 8	7
Loams	8–10	8– 9	8
Ordinary clays	12–16	9–14	9
Heavy clays and fine sands	18–24	12–15	11
Class IV traffic (less than 300 vehicles daily)			
Sand and gravel	6– 7	6– 7	6
Loams	7– 9	7– 8	7
Ordinary clays	10–15	8–12	8
Heavy clays and fine sands	15–22	10–14	9

TABLE 154.—COMPARISON OF RECOMMENDED THEORETICAL DEPTHS OF CEMENT-CONCRETE BASES FOR DIFFERENT PAVEMENTS UNDER DIFFERENT MAXIMUM LOADS ON DIFFERENT SOILS (IN INCHES)

NOTE.—The last column gives prevailing practice in base depth for each type (1919 to 1922).

Pavement	Recommended depths of cement-concrete bases based on modified corner-load formula $d = P\sqrt{\frac{JW}{S}}$ (Chap. VI)						Current practice 1919–1923, inches
	3½-ton truck 16,000-lb. gross load		5-ton truck 22,000-lb. gross load		7-ton truck 28,000-lb. gross load		
	Ordinary subsoils, inches	Gravel or macadam, inches	Ordinary subsoils, inches	Gravel or macadam, inches	Ordinary subsoils, inches	Gravel or macadam, subsoils, inches	
Plain concrete: (1:1½:3 mix)	7.2 & 7.8	6.5 & 7.0	7.9 & 8.8	7.2 & 8.0	8.7 & 9.7	8.0 & 8.8	6 to 10
Plain concrete: (1:2:4 mix)	7.6 & 8.2	6.9 & 7.4	8.4 & 9.2	7.6 & 8.3	9.2 & 10.0	8.4 & 9.1	
Reinforced concrete (mesh and bar): Central longitudinal joint (1:1½:3 mix)	6.3 & 6.9	6.0 & 6.4	6.7 & 7.5	6.2 & 6.8	7.3 & 8.2	6.5 & 7.3	
Reinforced concrete (corner and exterior tie bars only): Central longitudinal joint 1:1½:3 mix.	6.5 & 7.0	6.0 & 6.4	7.0 & 7.8	6.3 & 7.1	7.7 & 8.5	7.0 & 7.7	5 to 9
1:2:4 mix	6.9 & 7.4	6.4 & 6.8	7.4 & 8.2	6.7 & 7.4	8.1 & 9.0	7.4 & 8.1	
Monolithic brick 4-in. brick on 1:1½:3 concrete base	4.5	4.0	5.0	4.5	6.0	5.5	4.0

2-in. to 3-in. asphaltic concrete on concrete base:							
(1:3:6 mix)	6.5	6.0	7.0	6.3	7.5	6.8	5 to 8
(1:2½:5 mix)	6.0	6.0	6.5	6.0	7.0	6.3	
2-in. asphalt block on cement-concrete base:							
(1:2½:5 mix)	6.5	6.0	7.0	6.3	7.5	6.8	5 to 8
4-in. brick (mastic joint filler) on cement-concrete base:							
(1:3:6 mix)	6.8	6.2	7.6	6.9	8.3	7.5	
(1:2½:5 mix)	6.5	6.0	7.0	6.3	7.8	7.1	6 to 8
4-in. brick (cement grout filler):							
(1:3:6) concrete base	5.5	5.0	6.1	5.5	6.7	6.2	5 to 8
(1:2½:5) concrete base	5.2	5.0	5.7	5.2	6.3	5.7	
5-in. stone block: cement grout filler:							
(1:2½:5) concrete base	5.2	5.0	5.7	5.2	6.3	5.7	5 to 7

NOTE: Where two depths are given the smaller is for interior areas and the larger for exterior edge depths. Where one is given it applies to interior areas.

Typical recommended pavement sections showing details are given in Chap. VI under the discussion of each type of pavement. The object of this table is to give a tentative basis of estimating the amount of materials and the cost per square yard for the different types suitable for different maximum load conditions.

Table 154 in conjunction with Table 153, p. 959, **provides a means of computing reliable comparative cost estimates for all ordinary standard types based on equal strength.**

TABLE 155*A*.—LIMITING GRADES FOR DIFFERENT TYPES OF PAVEMENT

(Taken from Agg's "Roads and Pavements")

Surface Material	Per Cent
Wood block	3
Asphalt block	6
Brick	10
Sheet asphalt	5
Asphaltic concrete	7
Bituminous macadam (seal coat)	8
Bituminous macadam (no seal coat)	10
Cement concrete[1]	8
Hillside brick	12
Stone brick	12

TABLE 155*B*.

Surface Material	Per Cent
Wooden block	2
Asphalt block	4
Brick (grout joints)	5
Brick (mastic joints)	8
Concrete[1]	5 to 7
Bituminous macadam with flush or squeegee coat (In sandy country, 6% when coarse sand is sprinkled on surface.)	5
Bituminous macadam without squeegee	8
Waterbound macadam	8
"Hillside" brick	12
Stone block with open joints	12

[1] Hard to construct on grades over 5%.

Recommended Pavement Types.—Bituminous macadams are recommended for Class II traffic and resident village streets.

Water-bound macadam (oiled) for Class III traffic.

Concrete for Class I outside of villages.

Brick, for village business streets.

Stone block for hills on Class I traffic.

Asphalt block, for extremely heavy Class I traffic.

Sheet Asphalt, Topeka, etc., are to be avoided for original construction where traffic travels at high speed on account of skidding but its use for reconstruction has decided advantages from an economic standpoint and the use of coarse aggregate "Topeka or "Amiesite" reduces danger of skidding. Its most suitable location is a resident village or city street or for heavy slow traffic.

Templets.—For the convenience of the designer in drawing the shape of the finished road on the cross-sections, a number of trans-

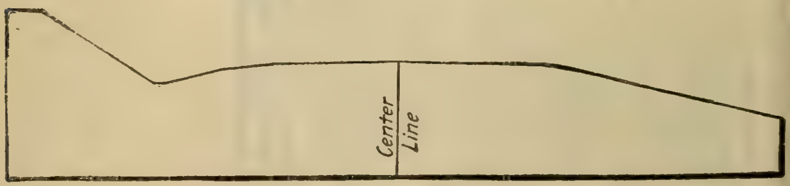
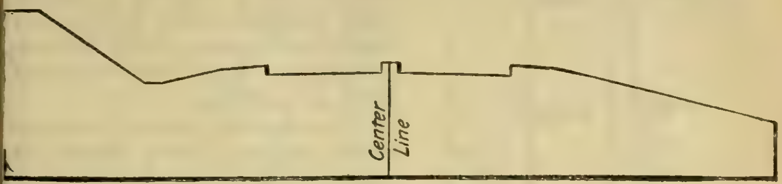
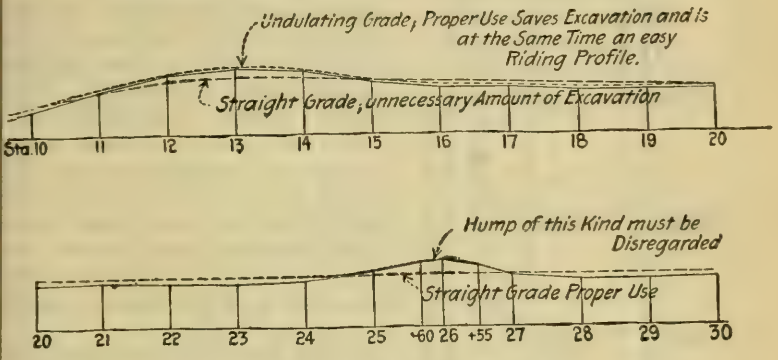


FIG. 311.—Transparent templet for use on cross-sections giving finished shape of road.

ɔarent composition templets are made, cut to proper scale, repre-
enting the different-shaped sections to be used (see Figs. 311 and
;12).



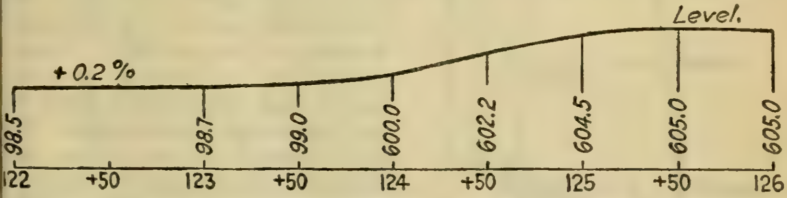
ᶠIG. 312.—Transparent templet with stone trench cut; saves time in drawing in sections for figuring cut and fill.



Illustrating Proper Use of
Straight and Undulating Grades

FIG. 313.

Economical Grade Line (New Construction).—On page 106, the nost economical grading conditions were mentioned. A convenent method of laying a grade line that will approximate these condiions is as follows: Take the case of determining an economical ɔrofile for a road from Stas. 11 to 16, where the grade can be placed



ᶠIG. 313*A*.—Actual profile road 5046 New York State, illustrating maximum abutness in short roll which is satisfactory for traffic.

ıt any desired elevation (see p. 964). Place the adopted templet ɔn each cross-section so that the cut will just make the fill (this posiion is estimated) and note the elevation of the center line of the ɔroposed finished road for this position of the templet; mark this :levation on the profile for each section between Stas. 11 and 16;

to connect these points would give the most economical grade line but this can rarely be done with a resulting smooth profile. Th adopted grade is obtained b drawing in a smooth grade lin that averages the elevation o these points and varies in eleva tion above and below them a little as possible.

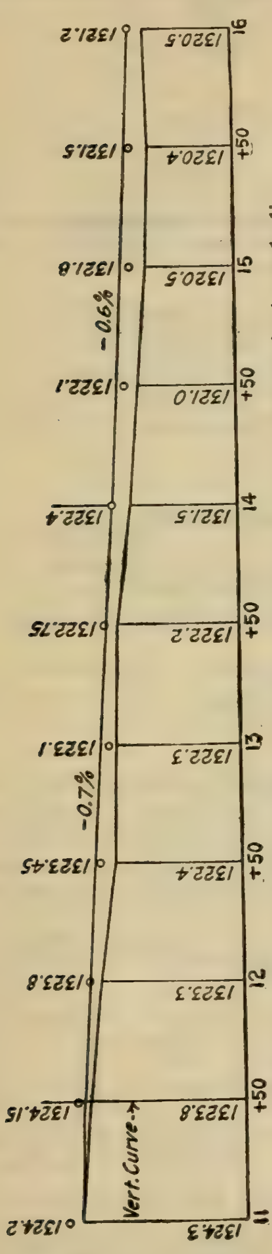


FIG. 314.—Sample profile illustrating method of placing economical grade line.

NOTE.—The small circles show the elevation of grade at each section that would make the proposed cut just make the proposed fill at that section.

The adopted grade elevation a each station is then figured, th shape of the finished road drawn to the cross-sections at these ele vations, and the excavation an embankment computed. If th ratio of cut to fill is not correct, th grade is raised or lowered slightl to produce the desired ratio. Th method is illustrated in Fig. 314.

For each stretch of road wher economy of grading governs th profile, this procedure is repeated and for the sections of road wher other considerations govern, th grade is placed at the require elevation and the borrow, waste or overhaul is figured.

Grade-line Reconstruction Designs.—The grade line for recon struction of old improved road follows the old grade line ver closely for most cases and the ele vation of the new pavement i adjusted to utilize to best advan tage the old pavement as a founda tion; that is, the earthwork of th shoulders and ditches does no govern the grade line as in ne construction and no effort is mad to balance cuts and fills. Exces excavation is wasted or ove hauled and excess fill is cared fo by borrow-pit excavation. Fo good typical reconstruction sec tions and relative grade of old an new pavements see Chap. VII Part I, Reconstruction.

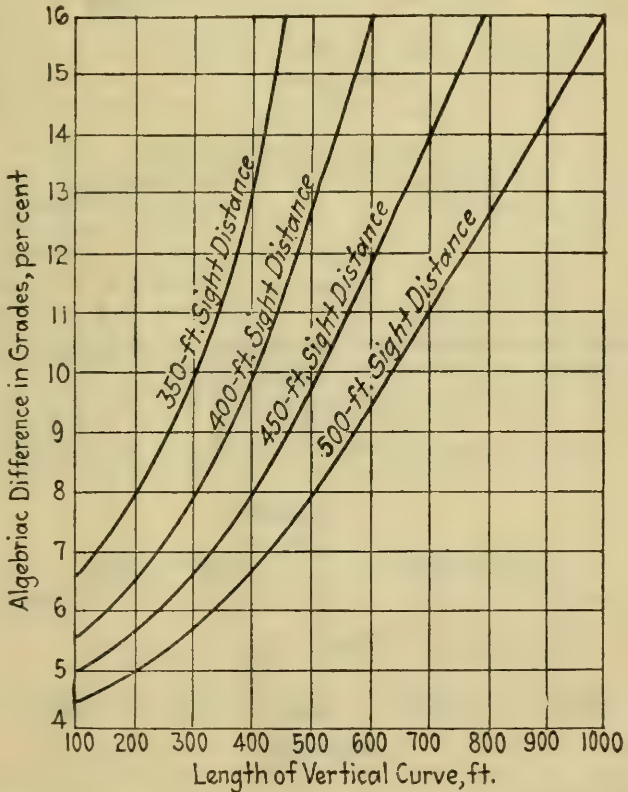
Vertical Curves.—To obtain smooth grade line, vertical curve are used at the intersection of th tangent rates of grade. Vertica curves are not usually used where the difference in gradient is les than one-half of 1%. Vertical curves should be made as long a

(text continued on page 966.)

ABLE 157.—RECOMMENDED MINIMUM LENGTHS OF VERTICAL CURVES BETWEEN TANGENT GRADES

Algebraic difference in rates of tangent grades, %	Minimum length of vertical curves on local service roads, feet	Minimum length of vertical curves on special service commercial roads, feet
5 or less	100	100–150
8	150	200
10	200	300
12	250	400
14	270	450
16	300	

NOTE.—Rough rule for minimum length of vertical curves:
100′ length for each 4% difference in gradients in hollows.
125′ length for each 4% difference in gradients at top of hills.
That is, if two ascending 6% grades are to be connected with a minimum-ngth vertical curve this rule would result in $\frac{12\%}{4\%} \times 125' = 375'$ length of ertical curve.



Required length of vertical curves for different sight distances J. S. Bureau Public Roads Standard. (Based on line of sight 5 ft. bove ground at both ends and tangent to road surface at middle.)

possible without needlessly increasing the grading; that is, for al normal cases they should follow the natural surface closely. Tabl 157 gives minimum lengths of vertical curves satisfactory from th standpoints of sight distance and easy-riding qualities.

For the final plans these vertical-curve elevations may be com puted by the following formulas, but for the trial grade line the can be scaled from the profile, drawing in the curve by means of regular curve templet, with which all modern offices are equippec and in all ordinary cases this graphic method serves for the fina grade line, as with reasonable care the elevations are closer tha can be constructed.

Vertical-curve Formulas. Formula A.—Difference in elevatio at center of curve. d expressed in feet = $\frac{1}{8}$ algebraic differenc of the tangent grades expressed in feet per 100 × length of curv expressed in stations of 100′.

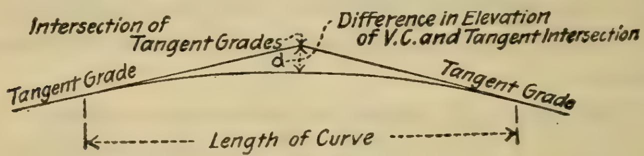


FIG. 315*A*.

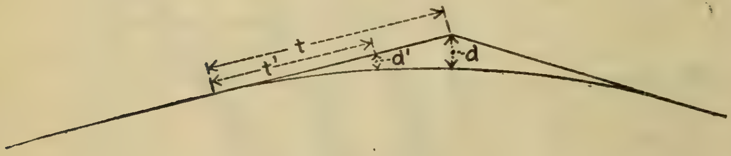


FIG. 315*B*.

Formula B.—Intermediate differences of elevations betwee tangent grades and points on vertical curve.

$$d' : d :: t'^2 : t^2$$

$$d' = \frac{dt'^2}{t^2}.$$

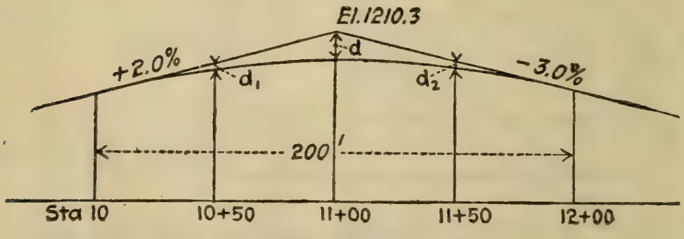


FIG. 315*C*.

Example of Vertical-curve Computation.—It is required to figur the vertical-curve elevations for a vertical curve 200′ long betweer

tangent grades of $+2.0$ and -3.0% meeting at Sta. 11 + 00 at an elevation of 1210.3.

First, find the middle correction d. Use Formula A.

$$d = \tfrac{1}{8}(2.0 - (-3.0)) \times (2)$$
$$d = \tfrac{1}{8}(5) \times (2) = \tfrac{10}{8} = 1.25'.$$

Second, determine the corrections d_1 and d_2. Use Formula B.

$$d_1 = \frac{dt'^2}{t^2} = 1.25 \frac{50^2}{100^2} = 1.25 \times \frac{1}{4} = 0.31'$$

$$d_2 = 1.25 \frac{50^2}{100^2} = 0.31'.$$

Third, determine the elevation of the tangent grades at 10 + 50 and 11 + 50.

Fourth, subtract the vertical-curve corrections d_1, d, and d_2 from these tangent grades at 10 + 50, 11 + 00, and 11 + 50.

Vertical-curve Elevations

Sta. 10 + 50 = tangent elevation 1209.3 − 0.31 = 1208.99
Sta. 11 + 00 = tangent elevation 1210.3 − 1.25 = 1209.05
Sta. 11 + 50 = tangent elevation 1208.8 − 0.31 = 1208.49

Table 158 is useful for draftsmen for picking out the correct curve to use in inking in the vertical curves. This table is compiled for a horizontal scale of 1″ = 50′, and a vertical scale of 1″ = 10′. For other scales a similar table can be constructed.

Explanation of Table 158.—Suppose it is required to pick out the correct curve templet to draw in a vertical curve 300′ long between two tangent grades having an algebraic difference of 5% (say a +2.0 and a − 3.0% grade). On the line opposite 5.0 in column 1 representing the algebraic difference of rate pick out the value 24 in the column headed 300′ curve; this means that a curve having a radius of 24″ will fit the conditions. This curve can be found easily from the collection of curve templets which have been previously marked with their radii in inches.

TABLE 158.—TABLE OF RADII FOR PLOTTING VERTICAL CURVES ON PROFILES

Algebraic Diff.	100′ Curve Rad.	200′ Curve Rad.	300′ Curve Rad.	400′ Curve Rad.
1.0	40	80	120	160
1.2	33	67	100	132
1.4	29	57	85	116
1.6	25	50	75	100
1.8	22	44	65	88
2.0	20	40	60	80
2.2	18	36	55	72
2.4	16½	33	50	66
2.6	15½	30	46	62
2.8	14½	29	43	58
3.0	13½	27	40	54
3.2	12½	25	37	50
3.4	12	23	35	48
3.6	11	22	33	44
3.8	10½	21	32	42
4.0	10	20	30	40
4.5	9	18	27	36
5.0	8	16	24	32
5.5	7	14½	22	28
6.0	6½	13½	20	26
7.0	6	11½	17	24
8.0	5	10	16	20
9.0	4½	9	13½	18
10.0	4	8	12	16
11.0	3½	7	11	14½
12.0	3½	6½	10	13½
13.0	3	6	9	12½
14.0	3	5½	8½	11½

NOTE.—*See page 967 for explanation of this table.*

TABLE 159.—REQUIRED MINIMUM LENGTH OF VERTICAL CURVES FOR A SPECIFIED SIGHT DISTANCE BASED ON A LINE OF SIGHT 5′ 6″ ABOVE THE GROUND AT BOTH ENDS

Algebraic difference in rates of grade per cent	Minimum length of vertical curve in feet for a sight distance of 250′	Minimum length of vertical curve in feet for a sight distance of 350′, in feet
6		
8	...	150
10	50	250
12	135	330
14	190	400
16	225	450

The limit of sight due to vertical curves is shown in Table 159.

Table 159 gives the distance ahead that a driver can see on a straight road, assuming that his eye is 5′ 06″ above the road, for vertical curves of 200, 150, and 100′ long between grades having a large difference of rate. See also diagram (p. 965) for length of curve required, assuming driver's eye 5′ above the road.

Example.—Suppose a $+5\%$ grade meets a -7% grade and that it is desired to put in the minimum length curve that will allow a sight ahead of 350′. The difference in gradient is $5 + 7 = 12\%$. From Table 159, opposite 12%, the length required can be readily picked; it will be about 330′, and 350′ would probably be used. It is rare that the sight distance governs in the selection of length of curve except for overhead railroad elimination projects. See also Table 157, page 965.

Placing the Templets and Planimetering the Areas.—After the trial grade line has been placed the center-line elevations of the proposed finished road are figured for each point on the profile where cross-sections have been taken, and the section selected is drawn on the original cross-sections at these elevations, using the templets mentioned on page 962.

Because it is comparatively easy to make a mistake of 1 or 5′ in elevation, the elevation of new grade, as shown by the position of the templet, should be checked from the profile before computing the cuts and fills.

Because of the small, irregular shape of these areas it is not possible to compute them arithmetically and the areas are determined by planimeters. Great care must be exercised if the work is to be reliable; a double run is made and the second run should be twice the first area. A certain limit of error in the second area is adopted.[1] This method is sufficiently accurate for preliminary estimating. On final estimate work, where the payment for earth excavation depends on the planimeter work, a satisfactory method is to have two men, using separate planimeters, compute the areas independently without any knowledge of each other's result. If the

[1] A satisfactory rule has been to allow a difference of 0.4 sq. ft. for areas up to 50 sq. ft., and 1.0-sq. ft. error above 50 sq. ft.

amount of excavation as figured separately varies more than 2%, a third run is made.

It is difficult to get accurate planimeter results because the work is monotonous, confining, and hard on the eyes, and the men tend to be careless unless they know that their work is being checked.

The temptation is strong to make the second reading equal twice the first, and unless some such method is used to check up, small errors will be passed over.

As a matter of interest, 3 miles of planimeter work, checked in this matter, was examined to see the average difference in areas where two careful men using different planimeters computed their results separately.

The sections used were plotted 1″ = 5′; areas read to nearest 0.1 sq. ft.

The average percentage of difference for single areas was:

	Per Cent of Difference
1. Small areas below 10 sq. ft.	5
2. Small areas 10–30 sq. ft.	2
3. Areas above 30 sq. ft.	1

These differences for single areas compensate, however, as some are above and some below the mean value, and computing the two separate results for the 3 miles gave the following result:

Percentage differences for work of two men for 3 miles, showing the reduction of error due to compensation:

	Per Cent of Difference
1. Small areas below 10 sq. ft.	1.0
2. Small areas 10–30 sq. ft.	0.5
3. Areas above 30 sq. ft.	0.05

The average excavation per mile will run about 3000 cu. yd. which means the average area of cut is about 16 sq. ft.

This comes under the second division and makes the probable error of final estimate planimeter work sufficiently close for all practical purposes.

Areas by Measuring the Depth of Cut or Fill at Intervals of 1′ across the Section.—It is often necessary for the field men to make a change in grade or alignment, and the following method of estimating section areas is convenient when no planimeter is available. The method is illustrated in the figures shown below.

Measure the depth of the cutting on vertical 1. Call this depth 1′. It can be readily seen that this depth is the average depth for the first foot of the cross-section, and if multiplied by 1 equals the area of the first foot of the section. In like manner measure the depth of the section on vertical 2. This is the average depth of the second foot of the section, and multiplied by 1′ equals the area of the second foot of the section. If the sum of the depths

, 2′, 3′, etc., is obtained for the entire width of the section, it is ident that the sum must equal the area of the section.

This summation can readily be made graphically, as shown low, by marking off on the edge of a piece of paper the successive pths.

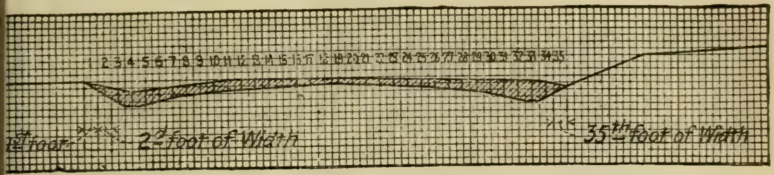


FIG. 316.

Scale the distance from the reference mark to the end mark, using ie same scale by which the cross-section is plotted and the area of ie section is obtained. This method is as reliable as planimeter ork, but is necessarily slower.

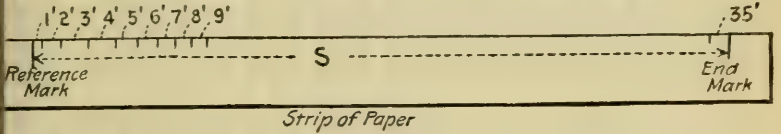


FIG. 317.

Computation of Earthwork.—Earthwork is usually computed om the planimeter results by the method of end areas; where 50′ ctions are used Table 160 is convenient.

Explanation of Table 160.—Suppose the area of excavation at, ay, Sta. 22 + 00 is 30.6 sq. ft.; suppose the excavation area at ta. 22 + 50 is 20.1 sq. ft. To get the number of cubic feet of xcavation from Stas. 22 + 00 to 22 + 50 add 30.6 + 20.1 = o.7. In Table 160 an area of 50.7 gives an excavation quantity f 1267.5 cu. ft. Where the normal cross-section interval is 50′ iis table is a great time saver.

Table 161 is convenient in changing cubic feet to cubic yards.

Table 162 is convenient for preliminary estimates, as it gives the ubic yards directly for the sum of the end areas in square feet. t, however, is not figured exactly and is not suitable for final stimate work.

Table 160.—Volume of 50′ Sections in Cubic Feet for Si of End Areas

COMPILED BY J. H. HUBER, ASSISTANT ENGINEER, BUFFALO, N. Y.

Sum of End Areas Sq. Ft.	0.0	0.1	0.2	0.3	0.4	0.5	0.6	0.7	0.8	0.9
0	—	2.5	5.0	7.5	10.0	12.5	15.0	17.5	20.0	22
1	25.0	27.5	30.0	32.5	35.0	37.5	40.0	42.5	45.0	47
2	50.0	52.5	55.0	57.5	60.0	62.5	65.0	67.5	70.0	72
3	75.0	77.5	80.0	82.5	85.0	87.5	90.0	92.5	95.0	97
4	100.0	102.5	105.0	107.5	110.0	112.5	115.0	117.5	120.0	122
5	125.0	127.5	130.0	132.5	135.0	137.5	140.0	142.5	145.0	147
6	150.0	152.5	155.0	157.5	160.0	162.5	165.0	167.5	170.0	172
7	175.0	177.5	180.0	182.5	185.0	187.5	190.0	192.5	195.0	197
8	200.0	202.5	205.0	207.5	210.0	212.5	215.0	217.5	220.0	222
9	225.0	227.5	230.0	232.5	235.0	237.5	240.0	242.5	245.0	247
10	250.0	252.5	255.0	257.5	260.0	262.5	265.0	267.5	270.0	272
11	275.0	277.5	280.0	282.5	285.0	287.5	290.0	292.5	295.0	297
12	300.0	302.5	305.0	307.5	310.0	312.5	315.0	317.5	320.0	322
13	325.0	327.5	330.0	332.5	335.0	337.5	340.0	342.5	345.0	347
14	350.0	352.5	355.0	357.5	360.0	362.5	365.0	367.5	370.0	372
15	375.0	377.5	380.0	382.5	385.0	387.5	390.0	392.5	395.0	397
16	400.0	402.5	405.0	407.5	410.0	412.5	415.0	417.5	420.0	422
17	425.0	427.5	430.0	432.5	435.0	437.5	440.0	442.5	445.0	447
18	450.0	452.5	455.0	457.5	460.0	462.5	465.0	467.5	470.0	472
19	475.0	477.5	480.0	482.5	485.0	487.5	490.0	492.5	495.0	497
20	500.0	502.5	505.0	507.5	510.0	512.5	515.0	517.5	520.0	522
21	525.0	527.5	530.0	532.5	535.0	537.5	540.0	542.5	545.0	547
22	550.0	552.5	555.0	557.5	560.0	562.5	565.0	567.5	570.0	572
23	575.0	577.5	580.0	582.5	585.0	587.5	590.0	592.5	595.0	597
24	600.0	602.5	605.0	607.5	610.0	612.5	615.0	617.5	620.0	622
25	625.0	627.5	630.0	632.5	635.0	637.5	640.0	642.5	645.0	647
26	650.0	652.5	655.0	657.5	660.0	662.5	665.0	667.5	670.0	672
27	675.0	677.5	680.0	682.5	685.0	687.5	690.0	692.5	695.0	697
28	700.0	702.5	705.0	707.5	710.0	712.5	715.0	717.5	720.0	722
29	725.0	727.5	730.0	732.5	735.0	737.5	740.0	742.5	745.0	747
30	750.0	752.5	755.0	757.5	760.0	762.5	765.0	767.5	770.0	772
31	775.0	777.5	780.0	782.5	785.0	787.5	790.0	792.5	795.0	797
32	800.0	802.5	805.0	807.5	810.0	812.5	815.0	817.5	820.0	822
33	825.0	827.5	830.0	832.5	835.0	837.5	840.0	842.5	845.0	847
34	850.0	852.5	855.0	857.5	860.0	862.5	865.0	867.5	870.0	872
35	875.0	877.5	880.0	882.5	885.0	887.5	890.0	892.5	895.0	897
36	900.0	902.5	905.0	907.5	910.0	912.5	915.0	917.5	920.0	922
37	925.0	927.5	930.0	932.5	935.0	937.5	940.0	942.5	945.0	947
38	950.0	952.5	955.0	957.5	960.0	962.5	965.0	967.5	970.0	972
39	975.0	977.5	980.0	982.5	985.0	987.5	990.0	992.5	995.0	997
40	1000.0	1002.5	1005.0	1007.5	1010.0	1012.5	1015.0	1017.5	1020.0	1022
41	1025.0	1027.5	1030.0	1032.5	1035.0	1037.5	1040.0	1042.5	1045.0	1047
42	1050.0	1052.5	1055.0	1057.5	1060.0	1062.5	1065.0	1067.5	1070.0	1072
43	1075.0	1077.5	1080.0	1082.5	1085.0	1087.5	1090.0	1092.5	1095.0	1097
44	1100.0	1102.5	1105.0	1107.5	1110.0	1112.5	1115.0	1117.5	1120.0	1122
45	1125.0	1127.5	1130.0	1132.5	1135.0	1137.5	1140.0	1142.5	1145.0	1147
46	1150.0	1152.5	1155.0	1157.5	1160.0	1162.5	1165.0	1167.5	1170.0	1172.
47	1175.0	1177.5	1180.0	1182.5	1185.0	1187.5	1190.0	1192.5	1195.0	1197.
48	1200.0	1202.5	1205.0	1207.5	1210.0	1212.5	1215.0	1217.5	1220.0	1222.
49	1225.0	1227.5	1230.0	1232.5	1235.0	1237.5	1240.0	1242.5	1245.0	1247.
50	1250.0	1252.5	1255.0	1257.5	1260.0	1262.5	1265.0	1267.5	1270.0	1272.

Note.—For volumes larger than those given, use figures in the table, movin decimal point one place to the right and add proportional part.

ABLE 160.—VOLUME OF 50′ SECTIONS IN CUBIC FEET FOR SUM OF END AREAS.—*Continued*

COMPILED BY J. H. HUBER, ASSISTANT ENGINEER, BUFFALO, N. Y.

Sum of nd Areas Sq. Ft.	0.0	0.1	0.2	0.3	0.4	0.5	0.6	0.7	0.8	0.9
50	1250.0	1252.5	1255.0	1257.5	1260.0	1262.5	1265.0	1267.5	1270.0	1272.5
51	1275.0	1277.5	1280.0	1282.5	1285.0	1287.5	1290.0	1292.5	1295.0	1297.5
52	1300.0	1302.5	1305.0	1307.5	1310.0	1312.5	1315.0	1317.5	1320.0	1322.5
53	1325.0	1327.5	1330.0	1332.5	1335.0	1337.5	1340.0	1342.5	1345.0	1347.5
54	1350.0	1352.5	1355.0	1357.5	1360.0	1362.5	1365.0	1367.5	1370.0	1372.5
55	1375.0	1377.5	1380.0	1382.5	1385.0	1387.5	1390.0	1392.5	1395.0	1397.5
56	1400.0	1402.5	1405.0	1407.5	1410.0	1412.5	1415.0	1417.5	1420.0	1422.5
57	1425.0	1427.5	1430.0	1432.5	1435.0	1437.5	1440.0	1442.5	1445.0	1447.5
58	1450.0	1452.5	1455.0	1457.5	1460.0	1462.5	1465.0	1467.5	1470.0	1472.5
59	1475.0	1477.5	1480.0	1482.5	1485.0	1487.5	1490.0	1492.5	1495.0	1497.5
60	1500.0	1502.5	1505.0	1507.5	1510.0	1512.5	1515.0	1517.5	1520.0	1522.5
61	1525.0	1527.5	1530.0	1532.5	1535.0	1537.5	1540.0	1542.5	1545.0	1547.5
62	1550.0	1552.5	1555.0	1557.5	1560.0	1562.5	1565.0	1567.5	1570.0	1572.5
63	1575.0	1577.5	1580.0	1582.5	1585.0	1587.5	1590.0	1592.5	1595.0	1597.5
64	1600.0	1602.5	1605.0	1607.5	1610.0	1612.5	1615.0	1617.5	1620.0	1622.5
65	1625.0	1627.5	1630.0	1632.5	1635.0	1637.5	1640.0	1642.5	1645.0	1647.5
66	1650.0	1652.5	1655.0	1657.5	1660.0	1662.5	1665.0	1667.5	1670.0	1672.5
67	1675.0	1677.5	1680.0	1682.5	1685.0	1687.5	1690.0	1692.5	1695.0	1697.5
68	1700.0	1702.5	1705.0	1707.5	1710.0	1712.5	1715.0	1717.5	1720.0	1722.5
69	1725.0	1727.5	1730.0	1732.5	1735.0	1737.5	1740.0	1742.5	1745.0	1747.5
70	1750.0	1752.5	1755.0	1757.5	1760.0	1762.5	1765.0	1767.5	1770.0	1772.5
71	1775.0	1777.5	1780.0	1782.5	1785.0	1787.5	1790.0	1792.5	1795.0	1797.5
72	1800.0	1802.5	1805.0	1807.5	1810.0	1812.5	1815.0	1817.5	1820.0	1822.5
73	1825.0	1827.5	1830.0	1832.5	1835.0	1837.5	1840.0	1842.5	1845.0	1847.5
74	1850.0	1852.5	1855.0	1857.5	1860.0	1862.5	1865.0	1867.5	1870.0	1872.5
75	1875.0	1877.5	1880.0	1882.5	1885.0	1887.5	1890.0	1892.5	1895.0	1897.5
76	1900.0	1902.5	1905.0	1907.5	1910.0	1912.5	1915.0	1917.5	1920.0	1922.5
77	1925.0	1927.5	1930.0	1932.5	1935.0	1937.5	1940.0	1942.5	1945.0	1947.5
78	1950.0	1952.5	1955.0	1957.5	1960.0	1962.5	1965.0	1967.5	1970.0	1972.5
79	1975.0	1977.5	1980.0	1982.5	1985.0	1987.5	1990.0	1992.5	1995.0	1997.5
80	2000.0	2002.5	2005.0	2007.5	2010.0	2012.5	2015.0	2017.5	2020.0	2022.5
81	2025.0	2027.5	2030.0	2032.5	2035.0	2037.5	2040.0	2042.5	2045.0	2047.5
82	2050.0	2052.5	2055.0	2057.5	2060.0	2062.5	2065.0	2067.5	2070.0	2072.5
83	2075.0	2077.5	2080.0	2082.5	2085.0	2087.5	2090.0	2092.5	2095.0	2097.5
84	2100.0	2102.5	2105.0	2107.5	2110.0	2112.5	2115.0	2117.5	2120.0	2122.5
85	2125.0	2127.5	2130.0	2132.5	2135.0	2137.5	2140.0	2142.5	2145.0	2147.5
86	2150.0	2152.5	2155.0	2157.5	2160.0	2162.5	2165.0	2167.5	2170.0	2172.5
87	2175.0	2177.5	2180.0	2182.5	2185.0	2187.5	2190.0	2192.5	2195.0	2197.5
88	2200.0	2202.5	2205.0	2207.5	2210.0	2212.5	2215.0	2217.5	2220.0	2222.5
89	2225.0	2227.5	2230.0	2232.5	2235.0	2237.5	2240.0	2242.5	2245.0	2247.5
90	2250.0	2252.5	2255.0	2257.5	2260.0	2262.5	2265.0	2267.5	2270.0	2272.5
91	2275.0	2277.5	2280.0	2282.5	2285.0	2287.5	2290.0	2292.5	2295.0	2297.5
92	2300.0	2302.5	2305.0	2307.5	2310.0	2312.5	2315.0	2317.5	2320.0	2322.5
93	2325.0	2327.5	2330.0	2332.5	2335.0	2337.5	2340.0	2342.5	2345.0	2347.5
94	2350.0	2352.5	2355.0	2357.5	2360.0	2362.5	2365.0	2367.5	2370.0	2372.5
95	2375.0	2377.5	2380.0	2382.5	2385.0	2387.5	2390.0	2392.5	2395.0	2397.5
96	2400.0	2402.5	2405.0	2407.5	2410.0	2412.5	2415.0	2417.5	2420.0	2422.5
97	2425.0	2427.5	2430.0	2432.5	2435.0	2437.5	2440.0	2442.5	2445.0	2447.5
98	2450.0	2452.5	2455.0	2457.5	2460.0	2462.5	2465.0	2467.5	2470.0	2472.5
99	2475.0	2477.5	2480.0	2482.5	2485.0	2487.5	2490.0	2492.5	2495.0	2497.5
100	2500.0	2502.5	2505.0	2507.5	2510.0	2512.5	2515.0	2517.5	2520.0	2522.5

ROPORTIONAL PART	0.0	0.1	0.2	0.3	0.4	0.5	0.6	0.7	0.8	0.9
		2.5	5.0	7.5	10.0	12.5	15.0	17.5	20.0	22.5

TABLE 161.—CUBIC FEET AND CUBIC YARDS

0–1350		1350–2700		2700–4050		4050–5400	
Feet	Yds.	Feet	Yds.	Feet	Yds.	Feet	Yds.
27	1	77	51	2,727	101	77	151
54	2	1,404	2	54	2	4,104	2
81	3	31	3	81	3	31	3
108	4	58	4	2,808	4	58	4
35	5	85	5	35	5	85	5
62	6	1,512	6	62	6	4,212	6
89	7	39	7	89	7	39	7
216	8	66	8	2,916	8	66	8
43	9	93	9	43	9	93	9
70	10	1,620	60	70	110	4,320	160
97	1	47	1	97	1	47	1
324	2	74	2	3,024	2	74	2
51	3	1,701	3	51	3	4,401	3
78	4	28	4	78	4	28	4
405	5	55	5	3,105	5	55	5
32	6	82	6	32	6	82	6
59	7	1,809	7	59	7	4,509	7
86	8	36	8	86	8	36	8
513	9	63	9	3,213	9	63	9
40	20	90	70	40	120	90	170
67	1	1,917	1	67	1	4,617	1
94	2	44	2	94	2	44	2
621	3	71	3	3,321	3	71	3
48	4	98	4	48	4	98	4
75	5	2,025	5	75	5	4,725	5
702	6	52	6	3,402	6	52	6
29	7	79	7	29	7	79	7
56	8	2,106	8	56	8	4,806	8
83	9	33	9	83	9	33	9
810	30	60	80	3,510	130	60	180
37	1	87	1	37	1	87	1
64	2	2,214	2	64	2	4,914	2
91	3	41	3	91	3	41	3
918	4	68	4	3,618	4	68	4
45	5	95	5	45	5	95	5
72	6	2,322	6	72	6	5,022	6
99	7	49	7	99	7	49	7
1,026	8	76	8	3,726	8	76	8
53	9	2,403	9	53	9	5,103	9
80	40	30	90	80	140	30	190
1,107	1	57	1	3,807	1	57	1
34	2	84	2	34	2	84	2
61	3	2,511	3	61	3	5,211	3
88	4	38	4	88	4	38	4
1,215	5	65	5	3,915	5	65	5
42	6	92	6	42	6	92	6
69	7	2,619	7	69	7	5,319	7
96	8	46	8	96	8	46	8
1,323	9	73	9	4,023	9	73	9
50	50	2,700	100	50	150	5,400	200

TABLE 161—*Continued*

5400–6750		6750–8100		8100–9450		9450–10,800	
Feet	Yds.	Feet	Yds.	Feet	Yds.	Feet	Yds.
5,427	201	77	251	8,127	301	77	351
54	2	6,804	2	54	2	9,504	2
81	3	31	3	81	3	31	3
5,508	4	58	4	8,208	4	58	4
35	5	85	5	35	5	85	5
62	6	6,912	6	62	6	9,612	6
89	7	39	7	89	7	39	7
5,616	8	66	8	8,316	8	66	8
43	9	93	9	43	9	93	9
70	210	7,020	260	70	310	9,720	360
97	1	47	1	97	1	47	1
5,724	2	74	2	8,424	2	74	2
51	3	7,101	3	51	3	9,801	3
78	4	28	4	78	4	28	4
5,805	5	55	5	8,505	5	55	5
32	6	82	6	32	6	82	6
59	7	7,209	7	59	7	9,909	7
86	8	36	8	86	8	36	8
5,913	9	63	9	8,613	9	63	9
40	220	90	270	40	320	90	370
67	1	7,317	1	67	1	10,017	1
94	2	44	2	94	2	44	2
6,021	3	71	3	8,721	3	71	3
48	4	98	4	48	4	98	4
75	5	7,425	5	75	5	10,125	5
6,102	6	52	6	8,802	6	52	6
29	7	79	7	29	7	79	7
56	8	7,506	8	56	8	10,206	8
83	9	33	9	83	9	33	9
6,210	230	60	280	8,910	330	60	380
37	1	87	1	37	1	87	1
64	2	7,614	2	64	2	10,314	2
91	3	41	3	91	3	41	3
6,318	4	68	4	9,018	4	68	4
45	5	95	5	45	5	95	5
72	6	7,722	6	72	6	10,422	6
99	7	49	7	99	7	49	7
6,426	8	76	8	9,126	8	76	8
53	9	7,803	9	53	9	10,503	9
80	240	30	290	80	340	30	390
6,507	1	57	1	9,207	1	57	1
34	2	84	2	34	2	84	2
61	3	7,911	3	61	3	10,611	3
88	4	38	4	88	4	38	4
6,615	5	65	5	9,315	5	65	5
42	6	92	6	42	6	92	6
69	7	8,019	7	69	7	10,719	7
96	8	46	8	96	8	46	8
6,723	9	73	9	9,423	9	73	9
50	250	8,100	300	50	350	10,800	400

TABLE 161—*Continued*

10,800–12,150		12,150–13,500		13,500–14,850		14,850–16,200	
Feet	Yds.	Feet	Yds.	Feet	Yds.	Feet	Yds.
10,827	401	77	451	13,527	501	177	551
54	2	12,204	2	54	2	14,904	2
81	3	31	3	81	3	31	3
10,908	4	58	4	13,608	4	58	4
35	5	85	5	35	5	85	5
62	6	12,312	6	62	6	15,012	6
89	7	39	7	89	7	39	7
11,016	8	66	8	13,716	8	66	8
43	9	93	9	43	9	93	9
70	410	12,420	460	70	510	15,120	560
97	1	47	1	97	1	47	1
11,124	2	74	2	13,824	2	74	2
51	3	12,501	3	51	3	15,201	3
78	4	28	4	78	4	28	4
11,205	5	55	5	13,905	5	55	5
32	6	82	6	32	6	82	6
59	7	12,609	7	59	7	15,309	7
86	8	36	8	86	8	36	8
11,313	9	63	9	14,013	9	63	9
40	420	90	470	40	520	90	570
67	1	12,717	1	67	1	15,417	1
94	2	44	2	94	2	44	2
11,421	3	71	3	14,121	3	71	3
48	4	98	4	48	4	98	4
75	5	12,825	5	75	5	15,525	5
11,502	6	52	6	14,202	6	52	6
29	7	79	7	29	7	79	7
56	8	12,906	8	56	8	15,606	8
83	9	33	9	83	9	33	9
11,610	430	60	480	14,310	530	60	580
37	1	87	1	37	1	87	1
64	2	13,014	2	64	2	15,714	2
91	3	41	3	91	3	41	3
11,718	4	68	4	14,418	4	68	4
45	5	95	5	45	5	95	5
72	6	13,122	6	72	6	15,822	6
99	7	49	7	99	7	49	7
11,826	8	76	8	14,526	8	76	8
53	9	13,203	9	53	9	15,903	9
80	440	30	490	80	540	30	590
11,907	1	57	1	14,607	1	57	1
34	2	84	2	34	2	84	2
61	3	13,311	3	61	3	16,011	3
88	4	38	4	88	4	38	4
12,015	5	65	5	14,715	5	65	5
42	6	92	6	42	6	92	6
69	7	13,419	7	69	7	16,119	7
96	8	46	8	96	8	46	8
12,123	9	73	9	14,823	9	73	9
50	450	13,500	500	50	550	16,200	600

TABLE 161—*Continued*

16,200–17,550		17,550–18,900		18,900–20,250		20,250–21,600	
Feet	Yds.	Feet	Yds.	Feet	Yds.	Feet	Yds.
16,227	601	77	651	18,927	701	77	751
54	2	17,604	2	54	2	20,304	2
81	3	31	3	81	3	31	3
16,308	4	58	4	19,008	4	58	4
35	5	85	5	35	5	85	5
62	6	17,712	6	62	6	20,412	6
89	7	39	7	89	7	39	7
16,416	8	66	8	19,116	8	66	8
43	9	93	9	43	9	93	9
70	610	17,820	660	70	710	20,520	760
97	1	47	1	97	1	47	1
16,524	2	74	2	19,224	2	74	2
51	3	17,901	3	51	3	20,601	3
78	4	28	4	78	4	28	4
16,605	5	55	5	19,305	5	55	5
32	6	82	6	32	6	82	6
59	7	18,009	7	59	7	20,709	7
86	8	36	8	86	8	36	8
16,713	9	63	9	19,413	9	63	9
40	620	90	670	40	720	90	770
67	1	18,117	1	67	1	20,817	1
94	2	44	2	94	2	44	2
16,821	3	71	3	19,521	3	71	3
48	4	98	4	48	4	98	4
75	5	18,225	5	75	5	20,925	5
16,902	6	52	6	19,602	6	52	6
29	7	79	7	29	7	79	7
56	8	18,306	8	56	8	21,006	8
83	9	33	9	83	9	33	9
17,010	630	60	680	19,710	730	60	780
37	1	87	1	37	1	87	1
64	2	18,414	2	64	2	21,114	2
91	3	41	3	91	3	41	3
17,118	4	68	4	19,818	4	68	4
45	5	95	5	45	5	95	5
72	6	18,522	6	72	6	21,222	6
99	7	49	7	99	7	49	7
17,226	8	76	8	19,926	8	76	8
53	9	18,603	9	53	9	21,303	9
80	640	30	690	80	740	30	790
17,307	1	57	1	20,007	1	57	1
34	2	84	2	34	2	84	2
61	3	18,711	3	61	3	21,411	3
88	4	38	4	88	4	38	4
17,415	5	65	5	20,115	5	65	5
42	6	92	6	42	6	92	6
69	7	18,819	7	69	7	21,519	7
96	8	46	8	96	8	46	8
17,523	9	73	9	20,223	9	73	9
50	650	18,900	700	50	750	21,600	800

TABLE 161—*Continued*

21,600–22,950		22,950–24,300		24,300–25,650		25,650–27,000	
Feet	Yds.	Feet	Yds.	Feet	Yds.	Feet	Yds.
21,627	801	77	851	24,327	901	77	951
54	2	23,004	2	54	2	25,704	2
81	3	31	3	81	3	31	3
21,708	4	58	4	24,408	4	58	4
35	5	85	5	35	5	85	5
62	6	23,112	6	62	6	25,812	6
89	7	39	7	89	7	39	7
21,816	8	66	8	24,516	8	66	8
43	9	93	9	43	9	93	9
70	810	23,220	860	70	910	25,920	960
97	1	47	1	97	1	47	1
21,924	2	74	2	24,624	2	74	2
51	3	23,301	3	51	3	26,001	3
78	4	28	4	78	4	28	4
22,005	5	55	5	24,705	5	55	5
32	6	82	6	32	6	82	6
50	7	23,409	7	59	7	26,109	7
86	8	36	8	86	8	36	8
22,113	9	63	9	24,813	9	63	9
40	820	90	870	40	920	90	970
67	1	23,517	1	67	1	26,217	1
94	2	44	2	94	2	44	2
22,221	3	71	3	24,921	3	71	3
48	4	98	4	48	4	98	4
75	5	23,625	5	75	5	26,325	5
22,302	6	52	6	25,002	6	52	6
29	7	79	7	29	7	79	7
56	8	23,706	8	56	8	26,406	8
83	9	33	9	83	9	33	9
22,410	830	60	880	25,110	930	60	980
37	1	87	1	37	1	87	1
64	2	23,814	2	64	2	26,514	2
91	3	41	3	91	3	41	3
22,518	4	68	4	25,218	4	68	4
45	5	95	5	45	5	95	5
72	6	23,922	6	72	6	26,622	6
99	7	49	7	99	7	49	7
22,626	8	76	8	25,326	8	76	8
53	9	24,003	9	53	9	26,703	9
80	840	30	890	80	940	30	990
22,707	1	57	1	25,407	1	57	1
34	2	84	2	34	2	84	2
61	3	24,111	3	61	3	26,811	3
88	4	38	4	88	4	38	4
22,815	5	65	5	25,515	5	65	5
42	6	92	6	42	6	92	6
69	7	24,219	7	69	7	26,919	7
96	8	46	8	96	8	46	8
22,923	9	73	9	25,623	9	73	9
50	850	24,300	900	50	950	27,000	1000

TABLE 161—*Continued*

27,000–28,350		28,350–29,700		29,700–31,050		31,050–32,400	
Feet	Yds.	Feet	Yds.	Feet	Yds.	Feet	Yds.
27,027	1001	77	1051	29,727	1101	77	1151
54	2	28,404	2	54	2	31,104	2
81	3	31	3	81	3	31	3
27,108	4	58	4	29,808	4	58	4
35	5	85	5	35	5	85	5
62	6	28,512	6	62	6	31,212	6
89	7	39	7	89	7	39	7
27,216	8	66	8	29,916	8	66	8
43	9	93	9	43	9	93	9
70	1010	28,620	1060	70	1110	31,320	1160
97	1	47	1	97	1	47	1
27,324	2	74	2	30,024	2	74	2
51	3	28,701	3	51	3	31,401	3
78	4	28	4	78	4	28	4
27,405	5	55	5	30,105	5	55	5
32	6	82	6	32	6	82	6
59	7	28,809	7	59	7	31,509	7
86	8	36	8	86	8	36	8
27,513	9	63	9	30,213	9	63	9
40	1020	90	1070	40	1120	90	1170
67	1	28,917	1	67	1	31,617	1
94	2	44	4	94	2	44	2
27,621	3	71	3	30,321	3	71	3
48	4	98	4	48	4	98	4
75	5	29,025	5	75	5	31,725	5
27,702	6	52	6	30,402	6	52	6
29	7	79	7	29	7	79	7
56	8	29,106	8	56	8	31,806	8
83	9	33	9	83	9	33	9
27,810	1030	60	1080	30,510	1130	60	1180
37	1	87	1	37	1	87	1
64	2	29,214	2	64	2	31,914	2
91	3	41	3	91	3	41	3
27,918	4	68	4	30,618	4	68	4
45	5	95	5	45	5	95	5
72	6	29,322	6	72	6	32,022	6
99	7	49	7	99	7	49	7
28,026	8	76	8	30,726	8	76	8
53	9	29,403	9	53	9	32,103	9
80	1040	30	1090	80	1140	30	1190
28,107	1	57	1	30,807	1	57	1
34	2	84	2	34	2	84	2
61	3	29,511	3	61	3	32,211	3
88	4	38	4	88	4	38	4
28,215	5	65	5	30,915	5	65	5
42	6	92	6	42	6	92	6
69	7	29,619	7	69	7	32,319	7
96	8	46	8	96	8	46	8
28,323	9	73	9	31,023	9	73	9
50	1050	29,700	1100	50	1150	32,400	1200

TABLE 161—*Continued*

32,400–33,750		33,750–35,100		35,100–36,450		36,450–37,800	
Feet	Yds.	Feet	Yds.	Feet	Yds.	Feet	Yds.
32,427	1201	77	1251	35,127	1301	77	1351
54	2	33,804	2	54	2	36,504	2
81	3	31	3	81	3	31	3
32,508	4	58	4	35,208	4	58	4
35	5	85	5	35	5	85	5
62	6	33,912	6	62	6	36,612	6
89	7	39	7	89	7	39	7
32,616	8	66	8	35,316	8	66	8
43	9	93	9	43	9	93	9
70	1210	34,020	1260	70	1310	36,720	1360
97	1	47	1	97	1	47	1
32,724	2	74	2	35,424	2	74	2
51	3	34,101	3	51	3	36,801	3
78	4	28	4	78	4	28	4
32,805	5	55	5	35,505	5	55	5
32	6	82	6	32	6	82	6
59	7	34,209	7	59	7	36,909	7
86	8	36	8	86	8	36	8
32,913	9	63	9	35,613	9	63	9
40	1220	90	1270	40	1320	90	1370
67	1	34,317	1	67	1	37,017	1
94	2	44	2	94	2	44	2
33,021	3	71	3	35,721	3	71	3
48	4	98	4	48	4	98	4
75	5	34,425	5	75	5	37,125	5
33,102	6	52	6	35,802	6	52	6
29	7	79	7	29	7	79	7
56	8	34,506	8	56	8	37,206	8
83	9	33	9	83	9	33	9
33,210	1230	60	1280	35,910	1330	60	1380
37	1	87	1	37	1	87	1
64	2	34,614	2	64	2	37,314	2
91	3	41	3	91	3	41	3
33,318	4	68	4	36,018	4	68	4
45	5	95	5	45	5	95	5
72	6	34,722	6	72	6	37,422	6
99	7	49	7	99	7	49	7
33,426	8	76	8	36,126	8	76	8
53	9	34,803	9	53	9	37,503	9
80	1240	30	1290	80	1340	30	1390
33,507	1	57	1	36,207	1	57	1
34	2	84	2	34	2	84	2
61	3	34,911	3	61	3	37,611	3
88	4	38	4	88	4	38	4
33,615	5	65	5	36,315	5	65	5
42	6	92	6	42	6	92	6
69	7	35,019	7	69	7	37,719	7
96	8	46	8	96	8	46	8
33,723	9	73	9	36,423	9	73	9
50	1250	35,100	1300	50	1350	37,800	1400

TABLE 161—*Concluded*

37,800–39,150		39,150–40,500		40,500–41,850		41,850–43,200	
Feet	Yds.	Feet	Yds.	Feet	Yds.	Feet	Yds.
37,827	1401	77	1451	40,527	1501	77	1551
54	2	39,204	2	54	2	41,904	2
81	3	31	3	81	3	31	3
37,908	4	58	4	40,608	4	58	4
35	5	85	5	35	5	85	5
62	6	39,312	6	62	6	42,012	6
89	7	39	7	89	7	39	7
38,016	8	66	8	40,716	8	66	8
43	9	93	9	43	9	93	9
70	1410	39,420	1460	70	1510	42,120	1560
97	1	47	1	97	1	47	1
38,124	2	74	2	40,824	2	74	2
51	3	39,501	3	51	3	42,201	3
78	4	28	4	78	4	28	4
38,205	5	55	5	40,905	5	55	5
32	6	82	6	32	6	82	6
59	7	39,609	7	59	7	42,309	7
86	8	36	8	86	8	36	8
38,313	9	63	9	41,013	9	63	9
40	1420	90	1470	40	1520	90	1570
67	1	39,717	1	67	1	42,417	1
94	2	44	2	94	2	44	2
38,421	3	71	3	41,121	3	71	3
48	4	98	4	48	4	98	4
75	5	39,825	5	75	5	42,525	5
38,502	6	52	6	41,202	6	52	6
29	7	79	7	29	7	79	7
56	8	39,906	8	56	8	42,606	8
83	9	33	9	83	9	33	9
38,610	1430	60	1480	41,310	1530	60	1580
37	1	87	1	37	1	87	1
64	2	40,014	2	64	2	42,714	2
91	3	41	3	91	3	41	3
38,718	4	68	4	41,418	4	68	4
45	5	95	5	45	5	95	5
72	6	40,122	6	/2	6	42,822	6
99	7	49	7	99	7	49	7
38,826	8	76	8	41,526	8	76	8
53	9	40,203	9	53	9	42,903	9
80	1440	30	1490	80	1540	30	1590
38,907	1	57	1	41,607	1	57	1
34	2	84	2	34	2	84	2
61	3	40 311	3	61	3	43,011	3
88	4	38	4	88	4	38	4
39,015	5	65	5	41,715	5	65	5
42	6	92	6	42	6	92	6
69	7	40,419	7	69	7	43,119	7
96	8	46	8	96	8	46	8
39,123	9	73	9	41,823	9	73	9
50	1450	40,500	1500	50	1550	43,200	1600

TABLE 162.—NEW YORK STATE DEPARTMENT OF HIGHWAYS EARTHWORK COMPUTATION TABLES

Distance horizontal. Sum of areas vertical. Quantities in cubic yards

2	3	4	5	6	7	8	9	10	11	12	13	14	D'uble Areas
0.0	0.1	0.1	0.1	0.1	0.1	0.1	0.2	0.2	0.2	0.2	0.2	0.3	1.0
0.0	0.1	0.1	0.1	0.1	0.2	0.2	0.2	0.2	0.2	0.3	0.3	0.3	2
0.1	0.1	0.1	0.1	0.2	0.2	0.2	0.2	0.3	0.3	0.3	0.3	0.4	4
0.1	0.1	0.1	0.1	0.2	0.2	0.2	0.3	0.3	0.3	0.4	0.4	0.4	6
0.1	0.1	0.1	0.2	0.2	0.2	0.3	0.3	0.3	0.4	0.4	0.4	0.5	8
0.1	0.1	0.1	0.2	0.2	0.3	0.3	0.3	0.4	0.4	0.4	0.5	0.5	2.0
0.1	0.1	0.2	0.2	0.2	0.3	0.3	0.4	0.4	0.4	0.5	0.5	0.6	2
0.1	0.1	0.2	0.2	0.3	0.3	0.4	0.4	0.4	0.5	0.5	0.6	0.6	4
0.1	0.1	0.2	0.2	0.3	0.3	0.4	0.4	0.5	0.5	0.6	0.6	0.7	6
0.1	0.2	0.2	0.3	0.3	0.4	0.4	0.5	0.5	0.6	0.6	0.7	0.7	8
0.1	0.2	0.2	0.3	0.3	0.4	0.4	0.5	0.6	0.6	0.7	0.7	0.8	3.0
0.1	0.2	0.2	0.3	0.4	0.4	0.5	0.5	0.6	0.7	0.7	0.8	0.8	2
0.1	0.2	0.3	0.3	0.4	0.4	0.5	0.6	0.6	0.7	0.8	0.8	0.9	4
0.1	0.2	0.3	0.3	0.4	0.5	0.5	0.6	0.7	0.7	0.8	0.9	0.9	6
0.1	0.2	0.3	0.4	0.4	0.5	0.6	0.6	0.7	0.8	0.8	0.9	1.0	8
0.1	0.2	0.3	0.4	0.4	0.5	0.6	0.7	0.7	0.8	0.9	1.0	1.0	4.0
0.2	0.2	0.3	0.4	0.5	0.5	0.6	0.7	0.8	0.9	0.9	1.0	1.1	2
0.2	0.2	0.3	0.4	0.5	0.6	0.7	0.7	0.8	0.9	1.0	1.1	1.1	4
0.2	0.3	0.3	0.4	0.5	0.6	0.7	0.8	0.9	0.9	1.0	1.1	1.2	6
0.2	0.3	0.4	0.4	0.5	0.6	0.7	0.8	0.9	1.0	1.1	1.2	1.2	8
0.2	0.3	0.4	0.5	0.6	0.6	0.7	0.8	0.9	1.0	1.1	1.2	1.3	5.0
0.2	0.3	0.4	0.5	0.6	0.7	0.8	0.9	1.0	1.1	1.2	1.3	1.3	2
0.2	0.3	0.4	0.5	0.6	0.7	0.8	0.9	1.0	1.1	1.2	1.3	1.4	4
0.2	0.3	0.4	0.5	0.6	0.7	0.8	0.9	1.0	1.1	1.2	1.3	1.5	6
0.2	0.3	0.4	0.5	0.6	0.8	0.9	1.0	1.1	1.2	1.3	1.4	1.5	8
0.2	0.3	0.4	0.6	0.7	0.8	0.9	1.0	1.1	1.2	1.3	1.4	1.6	6.0
0.2	0.3	0.5	0.6	0.7	0.8	0.9	1.1	1.1	1.3	1.4	1.5	1.6	2
0.2	0.4	0.5	0.6	0.7	0.8	0.9	1.1	1.2	1.3	1.4	1.5	1.7	4
0.2	0.4	0.5	0.6	0.7	0.9	1.0	1.1	1.2	1.3	1.5	1.6	1.7	6
0.3	0.4	0.5	0.6	0.7	0.9	1.0	1.1	1.3	1.4	1.5	1.6	1.8	8
0.3	0.4	0.5	0.6	0.8	0.9	1.0	1.2	1.3	1.4	1.6	1.7	1.8	7.0
0.3	0.4	0.5	0.7	0.8	0.9	1.1	1.2	1.3	1.5	1.6	1.7	1.9	2
0.3	0.4	0.5	0.7	0.8	1.0	1.1	1.2	1.4	1.5	1.6	1.8	1.9	4
0.3	0.4	0.6	0.7	0.8	1.0	1.1	1.3	1.4	1.5	1.7	1.8	2.0	6
0.3	0.4	0.6	0.7	0.9	1.0	1.2	1.3	1.4	1.6	1.7	1.9	2.0	8
0.3	0.4	0.6	0.7	0.9	1.0	1.2	1.3	1.5	1.6	1.8	1.9	2.1	8.0
0.3	0.5	0.6	0.8	0.9	1.1	1.2	1.4	1.5	1.7	1.8	2.0	2.1	2
0.3	0.5	0.6	0.8	0.9	1.1	1.2	1.4	1.6	1.7	1.9	2.0	2.2	4
0.3	0.5	0.6	0.8	1.0	1.1	1.3	1.4	1.6	1.7	1.9	2.1	2.2	6
0.3	0.5	0.7	0.8	1.0	1.1	1.3	1.5	1.6	1.8	2.0	2.1	2.3	8
0.3	0.5	0.7	0.9	1.0	1.2	1.3	1.5	1.7	1.8	2.0	2.2	2.3	9.0
0.3	0.5	0.7	0.9	1.0	1.2	1.4	1.5	1.7	1.9	2.0	2.2	2.4	2
0.3	0.5	0.7	0.9	1.0	1.2	1.4	1.6	1.7	1.9	2.1	2.3	2.4	4
0.4	0.5	0.7	0.9	1.1	1.2	1.4	1.6	1.8	2.0	2.1	2.3	2.5	6
0.4	0.5	0.7	0.9	1.1	1.3	1.5	1.6	1.8	2.0	2.2	2.4	2.5	8
0.4	0.6	0.7	0.9	1.1	1.3	1.5	1.7	1.9	2.0	2.2	2.4	2.6	10.0
0.4	0.6	0.8	1.0	1.2	1.4	1.6	1.8	1.9	2.1	2.3	2.5	2.7	5
0.4	0.6	0.8	1.0	1.2	1.4	1.6	1.8	2.0	2.2	2.4	2.6	2.9	11.0
0.4	0.6	0.9	1.1	1.3	1.5	1.7	1.9	2.1	2.3	2.5	2.8	3.0	5
0.4	0.7	0.9	1.1	1.3	1.6	1.8	2.0	2.2	2.4	2.7	2.9	3.1	12.0
0.5	0.7	0.9	1.2	1.4	1.6	1.9	2.1	2.3	2.5	2.8	3.0	3.2	5
0.5	0.7	1.0	1.2	1.5	1.7	2.0	2.2	2.4	2.6	2.9	3.1	3.4	13.0
0.5	0.7	1.0	1.3	1.5	1.8	2.0	2.3	2.5	2.7	3.0	3.3	3.5	5
0.5	0.8	1.0	1.3	1.6	1.8	2.1	2.3	2.6	2.8	3.1	3.4	3.6	14.0

TABLE 162.—*Continued*

5	16	17	18	19	20	21	22	23	24	25	26	27	D'uble Areas
0.3	0.3	0.3	0.3	0.4	0.4	0.4	0.4	0.4	0.4	0.5	0.5	0.5	1.0
0.3	0.4	0.4	0.4	0.4	0.4	0.5	0.5	0.5	0.5	0.6	0.6	0.6	2
0.4	0.4	0.4	0.5	0.5	0.5	0.5	0.6	0.6	0.6	0.6	0.7	0.7	4
0.4	0.5	0.5	0.5	0.6	0.6	0.6	0.7	0.7	0.7	0.7	0.8	0.8	6
0.5	0.5	0.6	0.6	0.6	0.7	0.7	0.7	0.8	0.8	0.8	0.9	0.9	8
0.6	0.6	0.6	0.7	0.7	0.7	0.8	0.8	0.9	0.9	0.9	1.0	1.0	2.0
0.6	0.7	0.7	0.7	0.8	0.8	0.9	0.9	0.9	1.0	1.0	1.1	1.1	2
0.7	0.7	0.8	0.8	0.8	0.9	0.9	1.0	1.0	1.1	1.1	1.2	1.2	4
0.7	0.8	0.8	0.9	0.9	1.0	1.0	1.1	1.1	1.2	1.2	1.3	1.3	6
0.8	0.8	0.9	1.0	1.0	1.0	1.1	1.1	1.2	1.2	1.3	1.4	1.4	8
0.8	0.9	0.9	1.0	1.1	1.1	1.2	1.2	1.3	1.3	1.4	1.4	1.5	3.0
0.9	0.9	1.0	1.1	1.1	1.2	1.2	1.3	1.4	1.4	1.5	1.5	1.6	2
0.9	1.0	1.1	1.1	1.2	1.3	1.3	1.4	1.4	1.5	1.6	1.6	1.7	4
1.0	1.1	1.1	1.2	1.3	1.3	1.4	1.5	1.5	1.6	1.7	1.7	1.8	6
1.1	1.1	1.2	1.3	1.3	1.4	1.5	1.5	1.6	1.7	1.8	1.8	1.9	8
1.1	1.2	1.3	1.3	1.4	1.5	1.6	1.6	1.7	1.8	1.9	1.9	2.0	4.0
1.2	1.2	1.3	1.4	1.5	1.6	1.6	1.7	1.8	1.9	1.9	2.0	2.1	2
1.2	1.3	1.4	1.5	1.5	1.6	1.7	1.8	1.9	2.0	2.0	2.1	2.2	4
1.3	1.4	1.4	1.5	1.6	1.7	1.8	1.9	2.0	2.0	2.1	2.2	2.3	6
1.3	1.4	1.5	1.6	1.7	1.8	1.8	2.0	2.0	2.1	2.2	2.3	2.4	8
1.4	1.5	1.6	1.7	1.8	1.9	1.9	2.0	2.1	2.2	2.3	2.4	2.5	5.0
1.4	1.5	1.6	1.7	1.8	1.9	2.0	2.1	2.2	2.3	2.4	2.5	2.6	2
1.5	1.6	1.7	1.8	1.9	2.0	2.1	2.2	2.3	2.4	2.5	2.6	2.7	4
1.6	1.7	1.8	1.9	2.0	2.1	2.2	2.3	2.4	2.5	2.6	2.7	2.8	6
1.6	1.7	1.8	2.0	2.0	2.2	2.3	2.4	2.5	2.6	2.7	2.8	2.9	8
1.7	1.8	1.9	2.0	2.1	2.2	2.3	2.4	2.6	2.7	2.8	2.9	3.0	6.0
1.7	1.8	1.9	2.1	2.2	2.3	2.4	2.5	2.6	2.8	2.9	3.0	3.1	2
1.8	1.9	2.0	2.1	2.2	2.4	2.5	2.6	2.7	2.8	3.0	3.1	3.2	4
1.8	2.0	2.1	2.2	2.3	2.5	2.6	2.7	2.8	2.9	3.1	3.2	3.3	6
1.9	2.0	2.1	2.3	2.4	2.5	2.6	2.8	2.9	3.0	3.2	3.3	3.4	8
1.9	2.1	2.2	2.3	2.5	2.6	2.7	2.9	3.0	3.1	3.2	3.4	3.5	7.0
2.0	2.1	2.3	2.4	2.5	2.7	2.8	2.9	3.1	3.2	3.3	3.5	3.6	2
2.1	2.2	2.3	2.5	2.6	2.7	2.9	3.0	3.1	3.3	3.4	3.6	3.7	4
2.1	2.3	2.4	2.5	2.7	2.8	3.0	3.1	3.2	3.4	3.5	3.7	3.8	6
2.2	2.3	2.5	2.6	2.7	2.9	3.0	3.2	3.3	3.5	3.6	3.8	3.9	8
2.2	2.4	2.5	2.7	2.8	3.0	3.1	3.3	3.4	3.6	3.7	3.9	4.0	8.0
2.3	2.4	2.6	2.7	2.9	3.0	3.2	3.3	3.5	3.6	3.8	4.0	4.1	2
2.3	2.5	2.6	2.8	2.9	3.1	3.3	3.4	3.6	3.7	3.9	4.1	4.2	4
2.4	2.5	2.7	2.9	3.0	3.2	3.3	3.5	3.7	3.8	4.0	4.1	4.3	6
2.4	2.6	2.8	2.9	3.1	3.3	3.4	3.6	3.8	3.9	4.1	4.2	4.4	8
2.5	2.7	2.8	3.0	3.2	3.3	3.5	3.7	3.8	4.0	4.2	4.3	4.5	9.0
2.6	2.7	2.9	3.1	3.2	3.4	3.6	3.8	3.9	4.1	4.3	4.4	4.6	2
2.6	2.8	3.0	3.1	3.3	3.5	3.7	3.8	4.0	4.2	4.4	4.5	4.7	4
2.7	2.8	3.0	3.2	3.4	3.6	3.7	3.9	4.1	4.3	4.5	4.6	4.8	6
2.7	2.9	3.1	3.3	3.4	3.6	3.8	4.0	4.2	4.4	4.5	4.7	4.9	8
2.8	3.0	3.1	3.3	3.5	3.7	3.9	4.1	4.2	4.4	4.6	4.8	5.0	100
2.9	3.1	3.3	3.5	3.7	3.9	4.1	4.3	4.5	4.6	4.9	5.0	5.3	5
3.1	3.3	3.5	3.7	3.9	4.1	4.3	4.5	4.7	4.9	5.1	5.3	5.5	11.0
3.2	3.4	3.6	3.8	4.0	4.3	4.5	4.7	4.9	5.1	5.3	5.5	5.7	5
3.3	3.6	3.8	4.0	4.2	4.5	4.7	4.9	5.1	5.3	5.5	5.8	6.0	12.0
3.5	3.7	3.9	4.2	4.4	4.6	4.9	5.1	5.3	5.5	5.8	6.0	6.2	5
3.6	3.8	4.1	4.3	4.6	4.8	5.0	5.3	5.5	5.8	6.0	6.3	6.5	13.0
3.7	4.0	4.2	4.5	4.8	5.0	5.2	5.5	5.8	6.0	6 3	6.5	6.7	5
3.9	4.1	4.4	4.7	4.9	5.2	5.4	5.7	6.0	6.2	6.5	6.7	7.0	14.0

TABLE 162.—*Continued*

28	29	30	31	32	33	34	35	36	37	38	39	40	D'ut Are
0.5	0.5	0.6	0.6	0.6	0.6	0.6	0.7	0.7	0.7	0.7	0.7	0.7	1.
0.6	0.6	0.7	0.7	0.7	0.7	0.8	0.8	0.8	0.8	0.9	0.9	0.9	
0.7	0.8	0.8	0.8	0.8	0.9	0.9	0.9	0.9	1.0	1.0	1.0	1.0	
0.8	0.9	0.9	0.9	1.0	1.0	1.0	1.0	1.1	1.1	1.1	1.2	1.2	
0.9	1.0	1.0	1.0	1.1	1.1	1.2	1.2	1.2	1.2	1.3	1.3	1.3	
1.0	1.1	1.1	1.2	1.2	1.2	1.3	1.3	1.3	1.4	1.4	1.5	1.5	2.
1.1	1.2	1.2	1.3	1.3	1.3	1.4	1.4	1.5	1.5	1.6	1.6	1.6	
1.2	1.3	1.3	1.4	1.4	1.5	1.5	1.6	1.6	1.7	1.7	1.7	1.8	
1.4	1.4	1.4	1.5	1.5	1.6	1.6	1.7	1.7	1.8	1.8	1.9	1.9	
1.5	1.5	1.6	1.6	1.7	1.7	1.8	1.8	1.9	1.9	2.0	2.0	2.1	
1.6	1.6	1.7	1.7	1.8	1.8	1.9	1.9	2.0	2.1	2.1	2.2	2.2	3.
1.7	1.7	1.8	1.8	1.9	2.0	2.0	2.1	2.1	2.2	2.3	2.3	2.4	
1.8	1.8	1.9	2.0	2.0	2.1	2.1	2.2	2.3	2.3	2.4	2.5	2.5	
1.9	1.9	2.0	2.1	2.1	2.2	2.3	2.3	2.4	2.5	2.5	2.6	2.7	
2.0	2.0	2.1	2.2	2.3	2.3	2.4	2.5	2.5	2.6	2.7	2.8	2.8	
2.1	2.2	2.2	2.3	2.4	2.5	2.5	2.6	2.7	2.7	2.8	2.9	3.0	4.
2.2	2.3	2.3	2.4	2.5	2.6	2.6	2.7	2.8	2.9	3.0	3.0	3.1	
2.3	2.4	2.4	2.5	2.6	2.7	2.8	2.9	2.9	3.0	3.1	3.2	3.3	
2.4	2.5	2.6	2.6	2.7	2.8	2.9	3.0	3.1	3.2	3.2	3.3	3.4	
2.5	2.6	2.7	2.8	2.8	2.9	3.0	3.1	3.2	3.3	3.4	3.5	3.6	
2.6	2.7	2.8	2.9	3.0	3.1	3.1	3.2	3.3	3.4	3.5	3.6	3.7	5.
2.7	2.8	2.9	3.0	3.1	3.2	3.3	3.4	3.5	3.6	3.7	3.8	3.9	
2.8	2.9	3.0	3.1	3.2	3.3	3.4	3.5	3.6	3.7	3.8	3.9	4.0	
2.9	3.0	3.1	3.2	3.3	3.4	3.5	3.6	3.7	3.8	3.9	4.1	4.2	
3.0	3.1	3.2	3.3	3.4	3.6	3.7	3.8	3.9	4.0	4.1	4.2	4.3	
3.1	3.2	3.3	3.5	3.6	3.7	3.8	3.9	4.0	4.1	4.2	4.3	4.5	6.
3.2	3.3	3.5	3.6	3.7	3.8	3.9	4.0	4.1	4.3	4.4	4.5	4.6	
3.3	3.4	3.6	3.7	3.8	3.9	4.0	4.2	4.3	4.4	4.5	4.6	4.7	
3.4	3.5	3.7	3.8	3.9	4.0	4.2	4.3	4.4	4.5	4.7	4.8	4.9	
3.5	3.7	3.8	3.9	4.0	4.2	4.3	4.4	4.5	4.7	4.8	4.9	5.0	
3.6	3.8	3.9	4.0	4.2	4.3	4.4	4.5	4.7	4.8	4.9	5.1	5.2	7.
3.7	3.9	4.0	4.1	4.3	4.4	4.5	4.7	4.8	4.9	5.1	5.2	5.3	
3.8	4.0	4.1	4.3	4.4	4.5	4.7	4.8	4.9	5.1	5.2	5.4	5.5	
3.9	4.1	4.2	4.4	4.5	4.7	4.8	4.9	5.1	5.2	5.4	5.5	5.6	
4.0	4.2	4.3	4.5	4.6	4.8	4.9	5.1	5.2	5.4	5.5	5.6	5.8	
4.2	4.3	4.4	4.6	4.7	4.9	5.0	5.2	5.3	5.5	5.6	5.8	5.9	8.
4.3	4.4	4.6	4.7	4.9	5.0	5.2	5.3	5.5	5.6	5.8	5.9	6.1	
4.4	4.5	4.7	4.8	5.0	5.1	5.3	5.5	5.6	5.8	5.9	6.1	6.2	
4.5	4.6	4.8	4.9	5.1	5.3	5.4	5.6	5.7	5.9	6.1	6.2	6.4	
4.6	4.7	4.9	5.1	5.2	5.4	5.5	5.7	5.9	6.0	6.2	6.4	6.5	
4.7	4.8	5.0	5.2	5.3	5.5	5.7	5.8	6.0	6.2	6.3	6.5	6.7	9.
4.8	4.9	5.1	5.3	5.5	5.6	5.8	6.0	6.1	6.3	6.5	6.7	6.8	
4.9	5.1	5.2	5.4	5.6	5.8	5.9	6.1	6.3	6.5	6.6	6.8	7.0	
5.0	5.2	5.3	5.5	5.7	5.9	6.1	6.2	6.4	6.6	6.8	6.9	7.1	
5.1	5.3	5.5	5.6	5.8	6.0	6.2	6.3	6.5	6.7	6.9	7.1	7.3	
5.2	5.4	5.6	5.8	5.9	6.1	6.3	6.5	6.7	6.9	7.0	7.2	7.4	10.
5.4	5.6	5.8	6.0	6.2	6.4	6.6	6.8	7.0	7.2	7.4	7.6	7.8	
5.7	5.9	6.1	6.3	6.5	6.7	6.9	7.1	7.3	7.5	7.8	7.9	8.2	11.
6.0	6.2	6.4	6.6	6.8	7.0	7.2	7.5	7.7	7.9	8.1	8.3	8.5	
6.2	6.4	6.7	7.0	7.1	7.3	7.6	7.8	8.0	8.2	8.5	8.7	8.9	12.
6.5	6.7	7.0	7.2	7.4	7.7	7.9	8.1	8.3	8.6	8.8	9.0	9.3	
6.7	7.0	7.2	7.5	7.7	8.0	8.2	8.4	8.7	8.9	9.2	9.4	9.6	13.
7.0	7.3	7.5	7.8	8.0	8.3	8.5	8.8	9.0	9.3	9.5	9.8	10.0	
7.2	7.5	7.8	8.0	8.3	8.6	8.8	9.1	9.3	9.6	9.8	10.1	10.4	14.

TABLE 162.—*Continued*

41	42	43	44	45	46	47	48	49	50	75	100	D'uble Areas
0.8	0.8	0.8	0.8	0.8	0.9	0.9	0.9	0.9	0.9	1.4	1.9	1.0
0.9	0.9	1.0	1.0	1.0	1.0	1.0	1.1	1.1	1.1	1.6	2.2	2
1.1	1.1	1.1	1.1	1.2	1.2	1.2	1.2	1.3	1.3	1.9	2.6	4
1.2	1.2	1.3	1.3	1.3	1.4	1.4	1.4	1.5	1.5	2.2	3.0	6
1.4	1.4	1.4	1.5	1.5	1.5	1.6	1.6	1.6	1.7	2.5	3.3	8
1.5	1.6	1.6	1.6	1.7	1.7	1.7	1.8	1.8	1.8	2.8	3.7	2.0
1.7	1.7	1.8	1.8	1.8	1.9	1.9	2.0	2.0	2.0	3.1	4.1	2
1.8	1.9	1.9	2.0	2.0	2.0	2.1	2.1	2.2	2.2	3.3	4.4	4
2.0	2.0	2.1	2.1	2.2	2.2	2.3	2.3	2.4	2.4	3.6	4.8	6
2.1	2.2	2.2	2.3	2.3	2.4	2.4	2.5	2.5	2.6	3.9	5.2	8
2.3	2.3	2.4	2.4	2.5	2.6	2.6	2.7	2.7	2.8	4.2	5.6	3.0
2.4	2.5	2.6	2.6	2.7	2.7	2.8	2.9	2.9	3.0	4.4	5.9	2
2.6	2.6	2.7	2.8	2.8	2.9	3.0	3.0	3.1	3.2	4.7	6.3	4
2.7	2.8	2.9	2.9	3.0	3.1	3.1	3.2	3.3	3.3	5.0	6.7	6
2.9	3.0	3.0	3.1	3.2	3.2	3.3	3.4	3.5	3.5	5.3	7.0	8
3.0	3.1	3.2	3.3	3.3	3.4	3.5	3.6	3.6	3.7	5.6	7.4	4.0
3.2	3.3	3.4	3.4	3.5	3.6	3.7	3.7	3.8	3.9	5.9	7.9	2
3.3	3.4	3.5	3.6	3.7	3.8	3.8	3.9	4.0	4.1	6.1	8.2	4
3.5	3.6	3.7	3.8	3.8	3.9	4.0	4.1	4.2	4.3	6.4	8.5	6
3.6	3.7	3.8	3.9	4.0	4.1	4.2	4.3	4.4	4.5	6.7	8.9	8
3.8	3.9	4.0	4.1	4.2	4.3	4.4	4.5	4.5	4.6	7.0	9.3	5.0
4.0	4.1	4.1	4.2	4.3	4.4	4.5	4.6	4.7	4.8	7.2	9.7	2
4.1	4.2	4.3	4.4	4.5	4.6	4.7	4.8	4.9	5.0	7.5	10.0	4
4.3	4.4	4.5	4.6	4.7	4.8	4.9	5.0	5.1	5.2	7.8	0.4	6
4.4	4.5	4.6	4.7	4.8	4.9	5.0	5.1	5.2	5.4	8.1	0.8	8
4.6	4.7	4.8	4.9	5.0	5.1	5.2	5.3	5.4	5.6	8.3	1.1	6.0
4.7	4.8	4.9	5.0	5.2	5.3	5.4	5.5	5.6	5.7	8.6	1.5	2
4.9	5.0	5.1	5.2	5.3	5.5	5.6	5.7	5.8	5.9	8.9	1.8	4
5.0	5.1	5.2	5.4	5.5	5.6	5.7	5.9	6.0	6.1	9.2	2.2	6
5.2	5.3	5.4	5.5	5.7	5.8	5.9	6.0	6.2	6.3	9.5	2.6	8
5.3	5.4	5.6	5.7	5.8	5.9	6.1	6.2	6.3	6.5	9.7	3.0	7.0
5.5	5.6	5.7	5.8	6.0	6.1	6.3	6.4	6.5	6.7	10.0	3.4	2
5.6	5.7	5.9	6.0	6.2	6.3	6.4	6.6	6.7	6.8	0.3	3.7	4
5.8	5.9	6.0	6.2	6.3	6.5	6.6	6.7	6.9	7.0	0.6	4.1	6
5.9	6.1	6.2	6.3	6.5	6.6	6.8	6.9	7.1	7.2	0.8	4.4	8
6.1	6.2	6.4	6.5	6.7	6.8	7.0	7.1	7.2	7.4	11.1	4.8	8.0
6.2	6.3	6.5	6.6	6.8	7.0	7.1	7.3	7.4	7.6	1.4	5.2	2
6.4	6.5	6.7	6.8	7.0	7.2	7.3	7.5	7.6	7.8	1.7	5.6	4
6.5	6.7	6.8	7.0	7.2	7.3	7.5	7.7	7.8	8.0	2.0	6.0	6
6.7	6.9	7.0	7.2	7.3	7.5	7.7	7.8	8.0	8.2	2.2	6.3	8
6.8	7.0	7.2	7.3	7.5	7.7	7.8	8.0	8.2	8.3	12.5	6.6	9.0
7.0	7.2	7.3	7.5	7.7	7.8	8.0	8.2	8.3	8.5	2.8	7.0	2
7.1	7.3	7.5	7.7	7.8	8.0	8.2	8.4	8.5	8.7	3.1	7.4	4
7.3	7.5	7.6	7.8	8.0	8.2	8.3	8.5	8.7	8.9	3.3	7.8	6
7.4	7.6	7.8	8.0	8.2	8.4	8.5	8.7	8.9	9.1	3.6	8.2	8
7.6	7.8	8.0	8.1	8.3	8.5	8.7	8.9	9.1	9.3	13.9	8.5	10.0
8.0	8.2	8.4	8.6	8.8	8.9	9.1	9.3	9.5	9.7	4.6	9.5	5
8.3	8.5	8.7	8.9	9.2	9.4	9.6	9.8	10.0	10.2	5.3	20.3	11.0
8.7	8.9	9.1	9.4	9.6	9.8	10.0	10.2	0.4	0.7	6.0	1.3	5
9.1	9.3	9.5	9.8	10.0	10.2	0.4	0.7	0.9	1.1	6.7	2.2	12.0
9.5	9.7	10.0	10.2	10.4	10.6	10.8	11.1	11.4	11.6	17.4	23.2	5
9.9	10.1	0.4	0.6	0.8	1.1	1.3	1.6	1.8	2.1	8.0	4.1	13.0
10.3	0.5	0.8	1.0	1.3	1.5	1.8	2.0	2.3	2.5	8.8	5.0	5
0.6	0.9	1.2	1.4	1.7	1.9	2.2	2.4	2.7	3.0	9.4	6.0	14.0

TABLE 162.—*Continued*

2	3	4	5	6	7	8	9	10	11	12	13	14	D'uble Areas
0.5	0.8	1.1	1.3	1.6	1.9	2.1	2.4	2.7	3.0	3.2	3.5	3.8	14.5
0.6	0.8	1.1	1.4	1.7	2.0	2.2	2.5	2.8	3.1	3.3	3.6	3.9	15.0
0.6	0.9	1.2	1.5	1.7	2.0	2.3	2.6	2.9	3.2	3.4	3.7	4.0	5
0.6	0.9	1.2	1.5	1.8	2.1	2.4	2.7	3.0	3.3	3.6	3.8	4.1	16.0
0.6	0.9	1.2	1.5	1.8	2.1	2.4	2.7	3.1	3.4	3.7	4.0	4.3	5
0.6	0.9	1.3	1.6	1.9	2.2	2.5	2.8	3.1	3.5	3.8	4.1	4.4	17.0
0.6	1.0	1.3	1.6	2.0	2.3	2.6	2.9	3.2	3.6	3.9	4.2	4.5	5
0.7	1.0	1.3	1.7	2.0	2.3	2.7	3.0	3.3	3.7	4.0	4.3	4.7	18.0
0.7	1.0	1.4	1.7	2.1	2.4	2.7	3.1	3.4	3.8	4.1	4.4	4.8	5
0.7	1.1	1.4	1.8	2.1	2.5	2.8	3.2	3.5	3.9	4.2	4.6	4.9	19.0
0.7	1.1	1.4	1.8	2.2	2.5	2.9	3.2	3.6	4.0	4.3	4.7	5.0	5
0.7	1.1	1.5	1.9	2.2	2.6	3.0	3.3	3.7	4.1	4.4	4.8	5.2	20.0
0.8	1.2	1.6	2.0	2.3	2.7	3.1	3.5	3.9	4.3	4.7	5.1	5.4	1
0.8	1.2	1.6	2.0	2.4	2.8	3.3	3.7	4.1	4.5	4.9	5.3	5.7	2
0.9	1.3	1.7	2.1	2.6	3.0	3.4	3.8	4.3	4.7	5.1	5.5	6.0	3
0.9	1.3	1.8	2.2	2.7	3.1	3.6	4.0	4.4	4.9	5.3	5.8	6.2	4
0.9	1.4	1.9	2.3	2.8	3.2	3.7	4.2	4.6	5.1	5.6	6.0	6.5	25.0
1.0	1.4	1.9	2.4	2.9	3.4	3.9	4.3	4.8	5.3	5.8	6.3	6.7	6
1.0	1.5	2.0	2.5	3.0	3.5	4.0	4.5	5.0	5.5	6.0	6.5	7.0	7
1.0	1.6	2.1	2.6	3.1	3.6	4.2	4.7	5.2	5.7	6.2	6.7	7.3	8
1.1	1.6	2.1	2.7	3.2	3.8	4.3	4.8	5.4	5.9	6.4	7.0	7.5	9
1.1	1.7	2.2	2.8	3.3	3.9	4.4	5.0	5.5	6.1	6.7	7.2	7.8	30.0
1.2	1.7	2.3	2.9	3.4	4.0	4.6	5.2	5.7	6.3	6.9	7.5	8.0	1
1.2	1.8	2.4	3.0	3.6	4.2	4.7	5.3	6.0	6.5	7.1	7.7	8.3	2
1.2	1.8	2.4	3.0	3.7	4.3	4.9	5.5	6.1	6.7	7.3	8.0	8.6	3
1.3	1.9	2.5	3.1	3.8	4.4	5.0	5.7	6.3	6.9	7.5	8.2	8.8	4
1.3	1.9	2.6	3.2	3.9	4.5	5.2	5.8	6.5	7.1	7.8	8.4	9.1	35.0
1.3	2.0	2.7	3.3	4.0	4.7	5.3	6.0	6.7	7.3	8.0	8.7	9.3	6
1.4	2.1	2.7	3.4	4.1	4.8	5.5	6.2	6.9	7.5	8.2	8.9	9.6	7
1.4	2.1	2.8	3.5	4.2	4.9	5.6	6.3	7.0	7.7	8.4	9.2	9.8	8
1.4	2.2	2.9	3.6	4.3	5.0	5.8	6.5	7.2	7.9	8.7	9.4	10.1	9
1.5	2.2	3.0	3.7	4.4	5.2	5.9	6.7	7.4	8.1	8.9	9.7	0.4	40.0
1.5	2.3	3.0	3.8	4.5	5.3	6.1	6.8	7.6	8.3	9.1	9.9	0.6	1
1.6	2.3	3.1	3.9	4.7	5.4	6.2	7.0	7.8	8.5	9.3	10.1	0.9	2
1.6	2.4	3.2	4.0	4.8	5.6	6.4	7.2	8.0	8.8	9.6	10.4	1.2	3
1.6	2.4	3.3	4.1	4.9	5.7	6.5	7.3	8.2	9.0	9.8	10.6	11.4	4
1.7	2.5	3.3	4.2	5.0	5.8	6.7	7.5	8.3	9.2	10.0	0.9	1.7	45.0
1.7	2.6	3.4	4.3	5.1	6.0	6.8	7.7	8.5	9.4	0.2	1.1	1.9	6
1.7	2.6	3.5	4.3	5.2	6.1	7.0	7.8	8.7	9.6	0.5	1.3	2.2	7
1.8	2.7	3.6	4.4	5.3	6.2	7.1	8.0	8.9	9.8	0.7	1.6	2.4	8
1.8	2.7	3.6	4.5	5.4	6.4	7.3	8.2	9.1	10.0	10.9	11.8	12.7	9
1.8	2.8	3.7	4.6	5.6	6.5	7.4	8.3	9.3	0.2	1.1	2.1	2.9	50.0
1.9	2.9	3.9	4.8	5.8	6.7	7.7	8.7	9.6	0.6	1.6	2.5	3.5	2
2.0	3.0	4.0	5.0	6.0	7.0	8.0	9.0	10.0	1.0	2.0	3.0	4.0	4
2.1	3.1	4.1	5.2	6.2	7.3	8.3	9.3	0.4	1.4	2.5	3.5	4.5	6
2.2	3.2	4.3	5.4	6.4	7.5	8.6	9.7	10.7	11.8	12.9	13.9	15.0	8
2.2	3.3	4.4	5.5	6.7	7.8	8.9	10.0	1.1	2.2	3.3	4.4	5.5	60.0
2.3	3.4	4.6	5.7	6.9	8.0	9.2	0.3	1.5	2.6	3.8	4.9	6.1	2
2.4	3.6	4.7	5.9	7.1	8.3	9.5	0.7	1.9	3.0	4.2	5.4	6.6	4
2.4	3.7	4.9	6.1	7.3	8.6	9.8	1.0	2.2	3.4	4.7	5.9	7.1	6
2.5	3.8	5.0	6.3	7.5	8.8	10.1	11.4	12.6	13.8	15.1	16.4	17.6	8
2.6	3.9	5.2	6.5	7.8	9.1	10.4	1.7	3.0	4.3	5.5	6.8	8.2	70.0
2.7	4.0	5.3	6.7	8.0	9.3	10.7	2.0	3.4	4.7	6.0	7.3	8.6	2
2.7	4.1	5.5	6.9	8.2	9.6	10.9	2.3	3.7	5.1	6.5	7.8	9.2	4

TABLE 162.—*Continued*

15	16	17	18	19	20	21	22	23	24	25	26	27	D'uble Areas
4.0	4.3	4.6	4.8	5.1	5.4	5.6	5.9	6.2	6.5	6.7	6.9	7.3	14.5
4.2	4.4	4.7	5.0	5.3	5.6	5.8	6.1	6.4	6.7	6.9	7.2	7.5	15.0
4.3	4.6	4.9	5.2	5.5	5.7	6.0	6.3	6.6	6.9	7.2	7.5	7.8	5
4.5	4.7	5.0	5.3	5.6	5.9	6.2	6.5	6.8	7.1	7.4	7.7	8.0	16.0
4.6	4.9	5.2	5.5	5.8	6.1	6.4	6.7	7.0	7.3	7.7	8.0	8.3	5
4.7	5.1	5.3	5.7	6.0	6.3	6.6	6.9	7.2	7.6	7.9	8.2	8.5	17.0
4.9	5.2	5.5	5.8	6.2	6.5	6.8	7.1	7.5	7.8	8.1	8.4	8.8	5
5.0	5.3	5.7	6.0	6.3	6.7	7.0	7.4	7.7	8.0	8.4	8.7	9.0	18.0
5.1	5.5	5.8	6.2	6.5	6.8	7.2	7.5	7.9	8.2	8.6	8.9	9.3	5
5.3	5.6	6.0	6.3	6.7	7.0	7.4	7.7	8.1	8.5	8.8	9.2	9.5	19.0
5.4	5.8	6.1	6.5	6.8	7.2	7.6	7.9	8.3	8.7	9.0	9.4	9.8	5
5.6	5.9	6.3	6.7	7.0	7.4	7.8	8.2	8.5	8.9	9.3	9.7	10.0	20.0
5.8	6.2	6.6	7.0	7.4	7.8	8.2	8.6	9.0	9.3	9.7	10.1	0.5	1
6.1	6.5	6.9	7.3	7.7	8.1	8.6	9.0	9.4	9.8	10.2	0.6	1.0	2
6.4	6.8	7.2	7.7	8.1	8.5	8.9	9.4	9.8	10.2	0.6	1.1	1.5	3
6.7	7.1	7.5	8.0	8.4	8.9	9.3	9.8	10.2	10.7	11.1	11.6	12.0	4
7.0	7.4	7.9	8.3	8.8	9.3	9.7	10.2	0.7	1.1	1.6	2.1	2.5	25.0
7.2	7.7	8.2	8.7	9.1	9.6	10.1	0.6	1.1	1.6	2.0	2.5	3.0	6
7.5	8.0	8.5	9.0	9.5	10.0	0.5	1.0	1.5	2.0	2.5	3.0	3.5	7
7.8	8.3	8.8	9.3	9.8	0.4	0.9	1.4	1.9	2.4	3.0	3.5	4.0	8
8.1	8.6	9.1	9.7	10.2	10.7	11.3	11.8	12.4	12.9	13.4	13.9	14.5	9
8.3	8.9	9.5	10.0	0.5	1.1	1.7	2.2	2.8	3.3	3.9	4.5	5.0	30.0
8.6	9.2	9.8	0.3	0.9	1.5	2.1	2.6	3.2	3.8	4.3	4.9	5.5	1
8.9	9.5	10.1	0.7	1.3	1.9	2.5	3.0	3.6	4.2	4.8	5.4	6.0	2
9.2	9.8	0.4	1.0	1.6	2.2	2.9	3.5	4.1	4.7	5.3	5.9	6.5	3
9.5	10.1	10.7	11.3	12.0	12.6	13.3	13.9	14.5	15.1	15.7	16.4	17.0	4
9.7	0.3	1.0	1.7	2.3	2.9	3.6	4.3	4.9	5.5	6.2	6.9	7.5	35.0
10.0	0.7	1.3	2.0	2.7	3.3	4.0	4.7	5.3	6.0	6.7	7.3	8.0	6
0.3	0.9	1.7	2.3	3.0	3.7	4.4	5.1	5.8	6.5	7.1	7.8	8.5	7
0.6	1.3	2.0	2.7	3.4	4.1	4.8	5.5	6.2	6.9	7.6	8.3	9.0	8
10.8	11.6	12.3	13.0	13.7	14.5	15.2	15.9	16.6	17.3	18.1	18.8	19.5	9
1.2	1.8	2.6	3.3	4.1	4.8	5.6	6.3	7.1	7.8	8.5	9.3	20.0	40.0
1.4	2.1	2.9	3.7	4.4	5.2	6.0	6.7	7.5	8.1	9.0	9.7	0.5	1
1.7	2.4	3.2	4.0	4.8	5.5	6.3	7.1	7.9	8.7	9.4	20.2	1.0	2
2.0	2.7	3.5	4.3	5.1	5.9	6.7	7.5	8.3	9.1	9.9	0.7	1.5	3
12.2	13.1	13.9	14.7	15.5	16.3	17.1	17.9	18.7	19.6	20.4	21.2	22.0	4
2.5	3.3	4.2	5.0	5.9	6.7	7.5	8.3	9.2	20.0	0.8	1.7	2.5	45.0
2.9	3.6	4.5	5.3	6.2	7.1	7.9	8.7	9.6	0.4	1.3	2.2	3.0	6
3.1	3.9	4.9	5.7	6.5	7.4	8.3	9.1	20.1	0.9	1.7	2.6	3.5	7
3.4	4.2	5.1	6.0	6.9	7.8	8.7	9.6	0.4	1.3	2.2	3.2	4.0	8
13.6	14.5	15.4	16.3	17.2	18.1	19.1	20.0	20.8	21.8	22.7	23.6	24.5	9
3.9	4.8	5.7	6.7	7.6	8.5	9.5	0.4	1.3	2.3	3.2	4.1	5.0	50.0
4.4	5.4	6.4	7.4	8.3	9.3	20.2	1.2	2.2	3.2	4.1	5.1	6.0	2
5.0	6.0	7.0	8.0	9.0	20.0	1.0	2.0	3.0	4.0	5.0	6.0	7.0	4
5.6	6.6	7.6	8.7	9.7	0.8	1.8	2.8	3.8	4.8	5.9	6.9	8.0	6
16.1	17.2	18.3	19.4	20.4	21.5	22.5	23.6	24.7	25.7	26.8	27.8	29.0	8
6.7	7.8	8.9	20.0	1.1	2.2	3.4	4.4	5.6	6.6	7.7	8.8	30.0	60.0
7.2	8.4	9.5	0.7	1.8	2.9	4.2	5.2	6.4	7.6	8.7	9.8	1.0	2
7.8	8.9	20.2	1.4	2.5	3.7	4.9	6.0	7.3	8.4	9.6	30.8	2.0	4
8.4	9.5	0.8	2.0	3.2	4.4	5.7	6.8	8.1	9.3	30.6	1.7	3.0	6
18.9	20.1	21.4	22.6	23.9	25.2	26.4	27.7	29.0	30.2	31.5	32.7	34.0	8
9.4	0.7	2.0	3.4	4.6	5.9	7.2	8.5	9.8	1.1	2.4	3.7	5.0	70.0
20.0	1.4	2.6	4.0	5.4	6.7	8.0	9.4	30.7	2.0	3.4	4.6	6.0	2
06	1.8	3.3	4.7	6.0	7.4	8.8	30.2	1.5	2.9	4.3	5.7	7.0	4

TABLE 162.—*Continued*

28	29	30	31	32	33	34	35	36	37	38	39	40	D'uble Areas
7.5	7.8	8.1	8.3	8.6	8.8	9.1	9.4	9.7	9.9	10.2	10.5	10.7	14.5
7.8	8.0	8.3	8.6	8.9	9.2	9.5	9.7	10.0	10.3	0.6	0.9	1.1	15.0
8.0	8.3	8.6	8.9	9.2	9.5	9.8	10.0	0.3	0.6	0.9	1.2	1.5	5
8.3	8.6	8.9	9.2	9.5	9.8	10.1	0.3	0.7	1.0	1.3	1.6	1.9	16.0
8.5	8.9	9.2	9.5	9.8	10.1	0.4	0.7	1.0	1.3	1.6	1.9	2.2	5
8.8	9.1	9.4	9.8	10.1	10.4	10.7	11.0	11.3	11.7	11.9	12.3	12.6	17.0
9.1	9.4	9.7	10.1	0.4	0.7	1.0	1.3	1.7	2.0	2.3	2.6	3.0	5
9.3	9.7	10.0	0.3	0.7	1.0	1.3	1.7	2.0	2.3	2.7	3.0	3.3	18.0
9.6	9.9	0.3	0.6	1.0	1.3	1.7	2.0	2.3	2.7	3.0	3.3	3.7	5
9.8	10.2	0.5	0.9	1.3	1.6	1.9	2.3	2.7	3.0	3.3	3.7	4.1	19.0
10.1	10.5	10.8	11.2	11.6	11.9	12.3	12.6	13.0	13.3	13.7	14.1	14.4	5
0.4	0.7	1.1	1.5	1.9	2.2	2.6	2.9	3.3	3.7	4.1	4.5	4.8	20.0
0.9	1.3	1.7	2.1	2.5	2.8	3.2	3.6	4.0	4.4	4.8	5.2	5.5	1
1.4	1.8	2.2	2.6	3.1	3.4	3.9	4.2	4.7	5.1	5.5	5.9	6.3	2
1.9	2.4	2.8	3.2	3.6	4.1	4.5	4.9	5.3	5.7	6.2	6.6	7.1	3
12.5	12.9	13.3	13.8	14.2	14.7	15.1	15.5	16.0	16.4	16.9	17.3	17.8	4
2.9	3.4	3.9	4.4	4.8	5.3	5.7	6.2	6.7	7.1	7.6	8.1	8.5	25.0
3.5	3.9	4.4	4.9	5.4	5.9	6.4	6.8	7.3	7.9	8.3	8.8	9.3	6
4.0	4.5	5.0	5.5	6.0	6.5	7.0	7.5	8.0	8.5	9.0	9.5	20.0	7
4.5	5.1	5.5	6.1	6.6	7.1	7.6	8.1	8.7	9.2	9.7	20.2	0.7	8
15.1	15.5	16.1	16.6	17.2	17.7	18.3	18.8	19.3	19.9	20.4	20.9	21.5	9
5.5	6.1	6.7	7.2	7.8	8.3	8.9	9.4	9.9	20.6	1.2	1.7	2.2	30.0
6.1	6.6	7.2	7.8	8.4	8.9	9.5	20.1	20.7	1.2	1.8	2.4	2.9	1
6.6	7.2	7.7	8.3	8.9	9.6	20.2	0.6	1.3	1.9	2.5	3.2	3.7	2
7.1	7.7	8.3	8.9	9.5	20.2	0.7	1.4	1.9	2.6	3.2	3.8	4.4	3
17.6	18.3	18.9	19.5	20.2	20.8	21.4	22.0	22.7	23.3	23.8	24.6	25.2	4
8.1	8.7	9.5	20.1	0.7	1.3	2.1	2.7	3.3	3.9	4.7	5.3	5.9	35.0
8.7	9.3	20.0	0.7	1.3	1.9	2.7	3.3	3.9	4.6	5.3	6.0	6.7	6
9.2	9.9	0.6	1.2	1.9	2.6	3.2	3.9	4.6	5.3	6.0	6.7	7.4	7
9.7	20.4	1.1	1.8	2.5	3.2	3.9	4.6	5.3	6.0	6.7	7.4	8.1	8
20.2	20.9	21.7	22.3	23.2	23.8	24.6	25.3	25.9	26.7	27.4	28.2	28.9	9
0.7	1.4	2.2	2.9	3.7	4.4	5.2	5.9	6.6	7.4	8.1	8.8	9.6	40.0
1.3	1.9	2.8	3.6	4.3	5.1	5.7	6.5	7.3	8.1	8.8	9.6	30.4	1
1.8	2.6	3.3	4.2	4.8	5.6	6.4	7.2	7.9	8.7	9.6	30.3	1.0	2
2.3	3.1	3.8	4.7	5.4	6.2	7.1	7.8	8.6	9.4	30.2	1.1	1.8	3
22.8	23.6	24.4	25.2	26.1	26.8	27.7	28.4	29.3	30.2	30.9	31.7	32.6	4
3.3	4.2	5.0	5.8	6.6	7.5	8.4	9.2	9.9	0.8	1.7	2.5	3.4	45.0
3.8	4.7	5.6	6.4	7.2	8.1	8.9	9.8	30.6	1.5	2.4	3.2	4.1	6
4.3	5.2	6.1	6.9	7.8	8.7	9.6	30.4	1.3	2.2	3.0	3.9	4.8	7
4.8	5.7	6.7	7.6	8.4	9.3	30.2	1.1	2.0	2.8	3.7	4.7	5.5	8
25.4	26.3	27.2	28.2	29.0	29.9	30.8	31.7	32.6	33.6	34.5	35.4	36.3	9
5.9	6.8	7.8	8.7	9.6	30.5	1.4	2.4	3.4	4.2	5.2	6.2	7.1	50.0
6.9	7.8	8.8	9.8	30.8	1.7	2.7	3.7	4.6	5.6	6.6	7.5	8.5	2
7.9	8.9	9.9	30.9	2.0	3.0	4.0	5.0	5.9	6.9	8.0	9.0	40.0	4
9.0	30.1	31.1	2.1	3.2	4.2	5.2	6.2	7.3	8.3	9.4	40.4	1.5	6
30.1	31.1	32.2	33.2	34.4	35.4	36.5	37.5	38.6	39.6	40.8	41.8	42.9	8
1.1	2.2	3.3	4.4	5.6	6.6	7.7	8.9	40.0	41.1	2.2	3.4	4.4	60.0
2.1	3.2	4.4	5.6	6.7	7.8	9.0	40.1	1.3	2.4	3.6	4.8	5.9	2
3.2	4.4	5.5	6.6	7.8	9.1	40.2	1.4	2.6	3.8	5.0	6.2	7.4	4
4.2	5.4	6.6	7.8	9.1	40.2	1.5	2.7	3.9	5.2	6.4	7.6	8.8	6
35.2	36.4	37.7	39.0	40.2	41.5	42.8	44.0	45.2	46.5	47.8	49.0	50.4	8
6.3	7.6	8.8	40.1	1.4	2.8	4.0	5.4	6.6	8.0	9.2	50.5	1.8	70.0
7.3	8.7	9.9	1.3	2.6	4.0	5.3	6.6	8.0	9.2	50.6	2.0	3.3	2
8.4	9.7	41.1	2.5	3.8	5.2	6.6	7.9	9.4	50.7	2.1	3.4	4.8	4

TABLE 162.—*Continued*

41	42	43	44	45	46	47	48	49	50	75	100		D'uble Areas
11.0	11.3	11.5	11.8	12.1	12.3	12.6	12.9	13.1	13.4	20.2	26.8	—	14.5
1.4	1.7	1.9	2.2	2.5	2.8	3.0	3.3	3.6	3.9	0.8	7.8	—	15.0
1.8	2.1	2.3	2.6	2.9	3.2	3.5	3.8	4.1	4.4	1.5	8.7	—	5
2.1	2.4	2.7	3.0	3.3	3.6	3.9	4.2	4.5	4.8	2.2	9.6	—	16.0
2.5	2.8	3.1	3.4	3.7	4.1	4.3	4.7	4.9	5.3	2.8	30.5	—	5
12.9	13.2	13.5	13.8	14.2	14.5	14.8	15.1	15.4	15.7	23.6	31.4	—	17.0
3.3	3.6	3.9	4.3	4.6	4.9	5.2	5.5	5.9	6.2	4.3	2.4	—	5
3.7	4.0	4.3	4.7	5.0	5.3	5.7	6.0	6.3	6.7	4.9	3.3	—	18.0
4.1	4.4	4.7	5.1	5.4	5.7	6.1	6.4	6.7	7.1	5.7	4.2	—	5
4.4	4.7	5.1	5.5	5.8	6.1	6.5	6.9	7.2	7.6	6.4	5.2	—	19.0
14.8	15.1	15.5	15.9	16.3	16.6	16.9	17.3	17.7	18.1	27.1	36.1	—	5
5.2	5.5	5.9	6.3	6.7	7.1	7.4	7.7	8.1	8.5	7.8	7.0	—	20.0
5.9	6.3	6.7	7.1	7.5	7.9	8.3	8.7	9.0	9.5	9.2	8.8	—	1
6.7	7.1	7.5	7.9	8.3	8.7	9.1	9.5	9.9	20.4	30.6	40.7	—	2
7.5	7.9	8.3	8.7	9.1	9.6	20.0	20.4	20.8	1.3	1.9	2.6	—	3
18.2	18.6	19.1	19.5	20.0	20.4	20.8	21.3	21.8	22.2	33.2	44.4	—	4
9.0	9.5	9.9	20.3	0.8	1.3	1.7	2.2	2.7	3.2	4.7	6.2	—	25.0
9.7	20.2	20.7	1.2	1.7	2.2	2.6	3.1	3.6	4.1	6.1	8.2	—	6
20.5	1.0	1.5	2.0	2.5	3.0	3.5	4.0	4.5	5.0	7.5	50.0	—	7
1.3	1.8	2.3	2.8	3.3	3.8	4.4	4.8	5.4	5.9	8.8	1.8	—	8
22.0	22.6	23.1	23.7	24.2	24.7	25.2	25.8	26.3	26.8	40.3	53.7	—	9
2.8	3.3	3.8	4.4	5.0	5.5	6.1	6.7	7.2	7.8	1.6	5.5	—	30.0
3.5	4.1	4.7	5.2	5.8	6.4	6.9	7.6	8.1	8.7	3.2	7.3	—	1
4.3	4.8	5.4	6.1	6.6	7.2	7.8	8.4	9.1	9.6	4.4	9.2	—	2
5.0	5.7	6.3	6.8	7.5	8.1	8.7	9.3	9.9	30.6	5.8	61.0	—	3
25.7	26.4	27.0	27.7	28.3	28.9	29.6	30.2	30.8	31.4	47.2	62.9	—	4
6.6	7.2	7.8	8.5	9.2	9.8	30.4	1.1	1.7	2.4	8.6	4.8	—	35.0
7.3	8.0	8.6	9.3	30.0	30.6	1.3	2.0	2.6	3.3	9.9	6.7	—	6
8.1	8.8	9.4	30.1	0.8	1.5	2.2	2.8	3.6	4.3	51.4	8.5	—	7
8.8	9.6	30.2	1.0	1.6	2.4	3.1	3.7	4.5	5.2	2.8	70.4	—	8
29.6	30.4	31.0	31.7	32.5	33.2	33.8	34.6	35.4	36.1	54.1	72.1	—	9
30.4	1.2	1.8	2.6	3.3	4.0	4.8	5.6	6.3	7.0	5.5	4.0	—	40.0
1.2	1.8	2.6	3.4	4.2	4.8	5.6	6.4	7.2	8.0	6.9	5.8	—	1
1.8	2.7	3.4	4.2	5.0	5.8	6.6	7.3	8.2	8.9	8.3	7.8	—	2
2.6	3.4	4.2	5.0	5.8	6.6	7.4	8.2	9.0	9.8	9.6	9.6	—	3
33.4	34.2	35.0	35.8	36.7	37.4	38.3	39.2	39.9	40.8	61.1	81.5	—	4
4.2	4.9	5.8	6.7	7.4	8.3	9.2	9.9	40.7	1.6	2.4	3.4	—	45.0
4.8	5.7	6.6	7.4	8.3	9.1	40.0	40.9	1.7	2.6	3.8	5.1	—	6
5.7	6.6	7.4	8.3	9.2	40.0	0.9	1.8	2.7	3.5	5.3	7.0	—	7
6.4	7.3	8.2	9.2	40.0	0.8	1.7	2.6	3.5	4.4	6.7	8.9	—	8
37.2	38.1	39.0	39.9	40.8	41.7	42.6	43.5	44.4	45.3	68.1	90.6	—	9
7.9	8.8	9.8	40.7	1.6	2.6	3.5	4.4	5.3	6.4	9.3	2.6	—	50.0
9.5	40.4	41.3	2.3	3.3	4.2	5.2	6.2	7.2	8.2	72.2	6.3	—	2
41.0	2.0	3.0	4.0	5.0	6.0	7.0	8.0	9.0	50.0	5.0	100.0	—	4
2.5	3.5	4.6	5.6	6.6	7.7	8.7	9.8	50.8	1.8	7.8	03.6	—	6
44.1	45.2	46.2	47.3	48.4	49.4	50.5	51.5	52.6	53.7	80.5	107.3	—	8
5.6	6.7	7.8	8.9	50.0	51.1	2.2	3.3	4.4	5.5	3.4	11.0	—	60.0
7.1	8.2	9.4	50.5	1.6	2.8	4.0	5.1	6.2	7.4	6.1	14.8	—	2
8.6	9.7	50.9	2.1	3.3	4.5	5.7	6.9	8.1	9.3	8.9	18.6	—	4
50.2	51.3	2.5	3.7	5.0	6.1	7.4	8.6	9.9	61.1	91.7	22.1	—	6
51.6	52.8	54.1	55.4	56.7	58.0	59.2	60.4	61.7	63.0	94.5	125.9	—	8
3.1	4.4	5.7	7.0	8.3	9.6	60.9	2.2	3.5	4.8	7.2	29.5	—	70.0
4.7	6.0	7.3	8.6	60.0	61.3	2.6	4.0	5.4	6.6	100.0	33.2	—	2
6.2	7.6	8.9	60.3	1.7	3.1	4.4	5.8	7.2	8.6	02.0	37.1	—	4

TABLE 162.—*Continued*

2	3	4	5	6	7	8	9	10	11	12	13	14	D'uble Areas
2.8	4.2	5.6	7.0	8.5	9.9	11.3	12.7	14.1	15.5	16.9	18.3	19.7	76.0
2.9	4.3	5.8	7.2	8.7	10.1	1.6	3.0	4.5	5.9	7.4	8.8	20.2	8
3.0	4.4	5.9	7.4	8.9	0.4	1.9	3.3	4.9	6.3	7.8	9.3	0.8	80.0
3.0	4.6	6.1	7.6	9.1	0.7	2.2	3.7	5.2	6.7	8.2	9.8	1.3	2
3.1	4.7	6.2	7.8	9.3	0.9	2.5	4.0	5.6	7.1	8.7	20.2	1.7	4
3.2	4.8	6.4	8.0	9.6	11.2	12.7	14.3	15.9	17.5	19.1	20.7	22.3	6
3.3	4.9	6.5	8.1	9.8	1.4	3.1	4.7	6.3	7.9	9.5	1.2	2.8	8
3.3	5.0	6.7	8.3	10.0	1.7	3.3	5.0	6.7	8.3	20.0	1.7	3.4	90.0
3.4	5.1	6.8	8.5	0.2	1.9	3.6	5.4	7.1	8.7	0.4	2.1	3.8	2
3.5	5.2	7.0	8.7	0.5	2.2	3.9	5.7	7.4	9.2	0.8	2.6	4.4	4
3.5	5.3	7.1	8.9	10.7	12.5	14.2	16.0	17.8	19.5	21.3	23.1	24.9	6
3.6	5.4	7.3	9.1	0.9	2.7	4.5	6.4	8.2	9.9	1.8	3.6	5.4	8
3.7	5.6	7.4	9.3	1.1	3.0	4.8	6.7	8.5	20.4	2.2	4.1	6.0	100.0
3.9	5.8	7.8	9.7	1.7	3.6	5.5	7.5	9.5	1.4	3.3	5.3	7.2	05
4.1	6.1	8.1	10.2	2.2	4.3	6.3	8.4	20.4	2.4	4.4	6.5	8.6	10
4.3	6.4	8.5	10.7	12.8	14.9	17.0	19.1	21.3	23.4	25.5	27.7	29.8	15
4.4	6.7	8.9	1.1	3.3	5.5	7.8	20.0	2.3	4.4	6.6	8.8	31.2	20
4.6	6.9	9.2	1.6	3.9	6.2	8.5	0.8	3.2	5.4	7.7	30.2	2.4	125.0
4.8	7.2	9.6	2.1	4.5	6.9	9.3	1.7	4.1	6.5	8.8	1.4	3.7	30
5.0	7.5	10.0	2.5	5.0	7.5	20.0	2.5	5.0	7.5	9.9	2.5	5.0	35
5.2	7.8	10.4	12.9	15.5	18.2	20.8	23.4	25.9	28.5	31.1	33.7	36.4	40
5.4	8.0	0.7	3.4	6.1	8.8	1.5	4.2	6.8	9.5	2.2	4.8	7.6	45
5.6	8.3	1.1	3.9	6.7	9.5	2.3	5.0	7.8	30.6	3.4	6.2	8.8	150.0
5.7	8.6	1.5	4.3	7.2	20.1	2.9	5.8	8.7	1.6	4.5	7.3	40.2	55
5.9	8.9	1.9	4.8	7.8	0.7	3.7	6.7	9.6	2.6	5.6	8.5	1.5	60
6.1	9.2	12.3	15.3	18.3	21.4	24.4	27.5	30.6	33.6	36.6	39.7	42.8	65
6.3	9.5	2.6	5.8	8.9	2.1	5.2	8.3	1.5	4.6	7.7	40.9	4.1	70
6.5	9.7	3.0	6.2	9.4	2.7	5.9	9.2	2.4	5.6	8.9	2.1	5.5	175.0
6.7	10.0	3.3	6.7	20.0	3.3	6.7	30.0	3.3	6.7	40.0	3.3	6.6	80
6.9	0.3	3.7	7.1	0.6	4.0	7.4	0.9	4.2	7.7	1.2	4.5	8.0	85
7.0	10.5	14.1	17.6	21.2	24.6	28.2	31.7	35.2	38.7	42.2	45.7	49.3	90
7.2	0.8	4.5	8.1	1.6	5.2	8.8	2.5	6.2	9.7	3.3	7.0	50.5	95
7.4	1.1	4.9	8.5	2.2	5.9	9.6	3.4	7.1	40.8	4.4	8.2	1.9	200.0
7.8	1.7	5.6	9.5	3.4	7.2	31.1	5.0	8.9	2.8	6.7	50.5	4.4	10
8.1	2.2	6.3	20.4	4.4	8.5	2.6	6.7	40.8	4.8	8.8	3.0	7.1	20
8.5	12.7	17.1	21.3	25.6	29.8	34.1	38.4	42.6	46.8	51.1	55.4	59.6	30
8.9	3.3	7.7	2.2	6.6	31.1	5.6	40.0	4.4	8.8	3.3	7.8	62.1	40
9.2	3.9	8.5	3.1	7.8	2.4	7.0	1.7	6.4	50.9	5.6	60.2	4.8	250.0
9.6	4.5	9.3	4.1	8.9	3.7	8.5	3.4	8.2	2.9	7.8	2.7	7.4	60
10.0	5.0	20.0	5.0	30.0	5.0	9.9	5.0	50.0	5.0	60.0	4.9	70.0	70
10.4	15.6	20.7	25.9	31.1	36.3	41.4	46.7	51.9	57.0	62.2	67.4	72.5	80
0.8	6.1	1.4	6.8	2.2	7.6	3.0	8.3	3.8	9.1	4.4	9.8	5.2	90
1.1	6.7	2.2	7.8	3.3	8.8	4.4	50.0	5.6	61.1	6.8	72.2	7.9	300.0
1.5	7.2	2.9	8.6	4.4	40.2	5.9	1.8	7.4	3.1	8.8	4.5	80.4	10
1.9	7.8	3.6	9.6	5.5	1.4	7.4	3.3	9.3	5.2	71.1	7.0	3.0	20
12.2	18.3	24.4	30.6	36.6	42.8	48.8	55.0	61.2	67.2	73.3	79.4	85.6	30
2.6	8.9	5.2	1.4	7.7	4.1	50.5	6.7	2.9	9.2	5.5	81.8	8.2	40
3.0	9.5	5.9	2.4	8.8	5.3	1.8	8.3	4.8	71.3	7.8	4.2	90.8	350.0
3.3	20.0	6.6	3.3	9.9	6.6	3.4	60.0	6.8	3.3	80.0	6.8	3.3	60
3.7	0.6	7.4	4.3	41.1	7.9	4.8	1.6	8.5	5.3	2.1	9.0	6.0	70
14.1	21.2	28.2	35.2	42.2	49.2	56.3	63.3	70.3	77.4	84.3	91.5	98.5	80
4.4	1.6	8.8	6.1	3.3	50.6	7.8	5.0	2.3	9.4	6.6	3.9	101.1	90
4.8	2.2	9.6	7.1	4.4	1.8	9.2	6.7	4.1	81.5	8.9	6.3	3.6	400.0

TABLE 162.—*Continued*

15	16	17	18	19	20	21	22	23	24	25	26	27	D'uble Areas
21.2	22.5	23.9	25.3	26.7	28.2	29.6	31.0	32.4	33.8	35.2	36.6	38.0	76.0
1.7	3.1	4.6	6.0	7.4	8.9	30.3	1.8	3.2	4.7	6.0	7.5	9.0	8
2.2	3.7	5.2	6.7	8.2	9.6	1.1	2.6	4.1	5.6	7.0	8.5	40.0	80.0
2.8	4.3	5.8	7.3	8.9	30.4	1.8	3.4	4.9	6.4	7.9	9.4	1.0	2
3.3	4.8	6.4	8.0	9.6	1.2	2.7	4.2	5.8	7.3	8.8	40.4	2.0	4
23.8	25.5	27.1	28.6	30.2	31.8	33.4	35.0	36.6	38.2	39.8	41.4	43.0	6
4.4	6.1	7.7	9.3	0.9	2.6	4.2	5.8	7.5	9.1	40.7	2.3	4.0	8
5.0	6.7	8.3	30.0	1.7	3.4	5.0	6.6	8.4	40.0	1.6	3.3	5.0	90.0
5.6	7.2	8.9	0.6	2.3	4.1	5.8	7.5	9.2	0.9	2.6	4.3	6.0	2
6.1	7.8	9.6	1.3	3.1	4.8	6.5	8.2	40.0	1.8	3.5	5.2	7.0	4
26.7	28.4	30.2	32.0	33.7	35.5	37.3	39.0	40.8	42.7	44.4	46.2	48.0	6
7.2	9.0	0.8	2.6	4.4	6.3	8.0	9.8	1.7	3.6	5.4	7.1	9.0	8
7.8	9.6	1.5	3.3	5.2	7.0	8.9	40.8	2.6	4.4	6.3	8.1	50.0	100.0
9.2	31.2	3.0	5.0	7.0	8.9	40.8	2.7	4.7	6.6	8.5	50.5	2.5	05
30.6	2.6	4.6	6.6	8.7	40.7	2.7	4.7	6.8	8.8	50.9	2.9	5.0	10
32.0	34.1	36.2	38.4	40.5	42.6	44.7	46.8	48.9	51.0	53.2	55.4	57.5	15
3.3	5.5	7.7	9.9	2.2	4.4	6.6	8.8	51.0	3.3	5.5	7.8	60.0	20
4.6	7.0	9.3	41.6	3.9	6.3	8.6	50.9	3.2	5.5	7.8	60.1	2.5	125.0
6.1	8.5	40.9	3.3	5.7	8.2	50.5	2.9	5.3	7.8	60.2	2.6	5.0	30
7.5	40.0	2.5	5.0	7.5	50.0	2.5	5.0	7.5	60.0	2.5	5.0	7.5	35
38.8	41.4	44.0	46.6	49.2	51.8	54.4	57.0	59.6	62.2	64.8	67.4	70.0	40
40.2	2.9	5.6	8.3	51.0	3.7	6.3	9.0	61.7	4.4	7.0	9.8	2.5	45
1.6	4.4	7.2	9.9	2.8	5.7	8.2	61.1	3.9	6.6	9.3	72.2	5.0	150.0
3.0	5.9	8.7	51.6	4.5	7.6	60.3	3.1	6.0	8.8	71.8	4.6	7.5	55
4.4	7.3	50.4	3.3	6.2	9.3	2.1	5.1	8.1	71.1	4.0	7.0	80.0	60
45.8	48.8	52.	55.0	58.0	61.0	64.2	67.1	70.3	73.4	76.2	79.3	82.5	65
7.2	50.5	3.5	6.6	9.8	3.0	6.0	9.2	2.3	5.5	8.7	81.8	5.0	70
8.6	1.8	5.0	8.3	61.5	4.8	8.0	71.2	4.6	7.7	81.0	4.3	7.5	175.0
50.0	3.3	6.6	60.0	3.3	6.8	9.9	3.2	6.7	80.0	3.2	6.7	90.0	80
1.4	4.8	8.1	1.6	5.0	8.5	71.9	5.3	8.8	2.2	5.6	9.0	2.5	85
52.8	56.2	59.8	63.3	66.8	70.4	73.8	77.3	80.9	84.3	87.9	91.7	95.0	90
4.0	7.8	61.3	5.0	8.7	2.1	5.7	9.4	3.0	6.7	90.2	3.9	7.5	95
5.5	9.2	2.9	6.7	70.3	4.0	7.7	81.4	5.1	8.9	2.8	6.4	100.0	200.0
8.3	62.1	6.0	70.0	3.8	7.8	81.7	5.5	9.4	93.4	7.2	101.2	05.0	10
61.0	5.1	9.3	3.2	7.4	81.5	5.5	9.5	93.7	7.8	101.9	06.0	10.0	20
63.9	68.0	72.4	76.6	80.9	85.2	89.4	93.7	98.0	102.2	106.5	110.8	115.0	30
6.5	71.0	5.5	9.9	4.3	8.9	93.2	7.8	102.2	106.8	11.1	15.5	20.0	40
9.4	4.0	8.6	83.2	7.9	92.5	7.1	101.9	06.5	11.1	15.9	20.5	25.0	250.0
72.1	7.0	81.8	6.5	91.4	6.5	101.2	06.0	10.7	15.5	20.4	25.3	30.0	60
5.0	80.0	5.0	90.0	4.9	100.0	05.0	10.0	15.1	20.0	25.0	30.0	35.0	70
77.8	82.9	88.1	93.2	98.4	103.8	108.9	114.1	119.2	124.5	129.5	134.8	140.0	80
80.6	5.9	91.2	6.5	102.1	07.4	12.9	18.1	23.5	28.9	34.3	39.8	45.0	90
3.2	8.9	4.4	100.0	05.7	11.1	16.8	22.2	29.7	33.3	38.9	44.5	50.0	300.0
6.0	91.8	7.5	03.3	09.2	14.8	20.6	26.3	32.1	37.9	43.5	49.3	55.0	10
9.0	4.7	100.9	06.8	12.7	18.6	24.3	30.3	36.2	42.2	48.1	54.1	60.0	20
91.5	97.7	103.9	110.0	116.1	122.2	128.3	134.5	140.6	146.8	152.8	158.9	165.0	30
4.5	100.7	07.1	13.2	19.6	26.0	32.2	38.5	44.9	51.1	57.2	63.8	70.0	40
7.2	03.8	10.2	16.7	23.2	29.7	36.2	42.5	49.1	55.5	62.0	68.5	75.0	350.0
100.0	06.6	13.4	20.0	26.8	33.3	40.0	46.6	53.2	60.0	66.8	73.4	80.0	60
02.8	09.6	16.4	23.2	30.2	37.0	43.8	50.7	57.5	64.5	71.2	78.1	85.0	70
105.6	112.5	119.6	126.8	133.8	140.8	147.8	154.8	161.8	168.9	175.9	183.0	190.0	80
08.2	15.5	22.9	30.0	37.2	44.3	51.7	58.9	66.1	73.4	80.5	87.8	95.0	90
11.1	18.5	25.9	33.3	40.7	48.1	55.6	63.0	70.4	77.8	85.2	92.6	200.0	400.0

TABLE 162.—*Continued*

28	29	30	31	32	33	34	35	36	37	38	39	40	D'uble Areas
39.4	40.8	42.3	43.6	45.1	46.5	47.9	49.3	50.7	52.1	53.5	54.9	56.3	76.0
40.4	1.8	3.3	4.8	6.2	7.7	9.1	50.5	2.0	3.5	4.9	6.4	7.8	8
1.5	3.0	4.4	5.9	7.4	8.8	50.3	1.8	3.3	4.8	6.3	7.8	9.2	80.0
2.5	4.1	5.6	7.1	8.6	50.1	1.7	3.2	4.7	6.2	7.7	9.2	60.8	2
3.6	5.2	6.7	8.2	9.8	1.3	2.9	4.5	6.0	7.5	9.1	60.7	2.3	4
44.6	46.2	47.8	49.3	51.0	52.5	54.2	55.7	57.3	58.9	60.5	62.1	63.7	6
5.6	7.2	8.8	50.5	2.1	3.7	5.4	7.0	8.7	60.3	1.9	3.5	5.2	8
6.7	8.3	50.0	1.7	3.3	5.0	6.7	8.3	60.0	1.6	3.3	5.0	6.6	90.0
7.7	9.4	1.1	2.8	4.5	6.2	7.9	9.6	1.3	3.0	4.7	6.4	8.2	2
8.8	50.5	2.2	4.0	5.7	7.5	9.2	61.0	2.7	4.4	6.2	7.9	9.7	4
49.8	51.5	53.3	55.1	56.9	58.7	60.4	62.2	64.0	65.8	67.6	69.4	71.1	6
50.8	2.6	4.4	6.3	8.1	9.9	1.7	3.5	5.3	7.2	8.9	70.8	2.6	8
1.8	3.7	5.5	7.4	9.3	61.1	3.0	4.8	6.6	8.5	70.3	2.2	4.0	100.0
4.4	6.4	8.3	60.3	62.2	4.2	6.1	8.1	70.0	72.0	3.9	5.8	7.8	05
7.0	9.1	61.1	3.2	5.2	7.2	9.3	71.3	3.4	5.4	7.4	9.5	81.5	10
59.7	61.8	64.0	66.0	68.1	70.4	72.5	74.5	76.7	78.8	81.0	83.1	85.2	15
62.3	4.5	6.7	8.9	71.1	3.4	5.5	7.8	80.0	82.2	4.5	6.7	9.0	20
4.8	7.2	9.5	71.8	4.1	6.5	8.8	81.0	3.4	5.6	8.0	90.3	92.7	125.0
7.3	9.8	72.1	4.5	7.0	9.4	81.8	4.2	6.6	9.0	91.4	3.9	6.1	30
70.0	72.5	5.0	7.5	80.0	82.5	5.0	7.5	90.0	92.5	5.0	7.5	100.0	35
72.6	75.2	77.8	80.5	83.0	85.6	88.1	90.7	93.4	96.0	98.5	101.1	103.7	40
5.2	7.9	80.5	3.2	5.9	8.6	91.3	4.0	6.7	9.4	102.0	04.8	07.5	45
7.8	80.6	3.4	6.1	8.9	91.7	4.5	7.2	100.0	102.8	05.6	08.3	11.1	150.0
80.4	3.2	6.2	9.0	91.9	4.7	7.6	100.5	03.4	06.2	09.1	12.0	14.8	55
2.9	5.9	8.8	91.8	4.7	7.7	100.8	03.8	06.7	09.7	12.6	15.6	18.5	60
85.5	88.5	91.6	94.7	97.7	100.9	103.9	107.0	110.0	113.1	116.1	119.2	122.2	65
8.1	91.3	4.4	7.6	100.8	03.9	07.1	10.2	13.3	16.6	19.7	22.8	26.0	70
90.8	4.0	7.3	100.5	03.8	70.0	10.2	13.4	16.7	20.0	23.2	26.4	29.6	175.0
3.4	6.6	100.0	03.3	06.8	111.1	13.4	16.8	20.0	23.3	26.7	30.1	33.4	80
6.0	9.4	02.8	06.2	09.6	13.2	16.5	19.9	23.4	26.8	30.2	33.7	37.1	85
98.6	102.1	105.6	109.2	112.8	116.1	119.7	123.2	126.7	130.2	133.8	137.3	140.8	90
101.2	04.8	08.4	12.0	15.6	19.2	22.9	26.4	30.0	33.8	37.2	40.9	44.5	95
03.7	07.4	11.1	14.9	18.6	22.2	26.0	29.6	33.3	37.0	40.6	44.4	48.1	200.0
08.8	12.8	16.6	20.6	24.4	28.4	32.2	36.2	40.0	44.0	47.8	51.6	55.6	10
14.0	18.2	22.2	26.4	30.4	34.4	38.6	42.6	46.8	50.8	54.8	59.0	63.0	20
119.4	123.6	127.8	132.0	136.2	140.6	145.0	149.0	153.4	157.6	162.0	166.2	170.4	30
24.6	29.0	33.4	37.8	42.2	46.8	51.0	55.6	60.0	64.4	69.0	73.4	78.0	40
29.6	34.4	39.0	43.6	48.2	53.0	57.6	62.0	66.8	71.4	76.0	80.6	85.4	250.0
34.6	39.4	44.2	49.0	54.0	58.8	63.6	68.4	73.2	78.0	82.8	87.8	92.5	60
40.0	45.0	50.0	55.0	60.0	65.0	70.0	75.0	80.0	85.0	90.0	95.0	200.0	70
145.2	150.4	155.6	161.0	166.0	171.2	176.2	181.4	186.8	192.0	197.0	202.2	207.4	80
50.4	55.8	61.0	66.4	71.8	77.2	82.6	88.0	93.3	98.8	204.0	09.6	14.6	90
55.6	61.2	66.8	72.2	77.8	83.4	89.0	94.4	200.0	205.6	11.2	16.6	22.2	300.0
60.8	66.4	72.4	78.0	83.8	89.4	95.2	201.0	06.8	12.4	18.2	24.0	29.6	10
65.8	71.8	77.6	83.6	89.4	95.4	201.6	07.6	13.6	19.4	25.2	31.2	37.0	20
171.0	177.0	183.2	189.4	195.4	201.8	207.8	214.0	220.0	226.2	232.2	238.4	244.4	30
76.2	82.6	88.8	95.2	201.6	07.8	14.2	20.4	26.7	33.2	39.4	45.6	52.0	40
81.6	88.0	94.6	201.0	07.6	14.0	20.4	26.8	33.4	40.0	46.4	52.8	59.2	350.0
86.8	93.2	200.0	06.6	13.6	22.2	26.8	33.6	40.0	46.6	53.4	60.2	66.8	60
92.0	98.8	05.6	12.4	19.2	26.4	33.0	39.8	46.8	53.6	60.4	67.4	74.2	70
197.2	204.2	211.2	218.4	225.6	232.2	239.4	246.4	253.4	260.4	267.6	274.6	281.6	80
202.4	09.6	16.8	24.0	31.2	38.4	45.8	52.8	60.2	67.6	74.4	81.8	89.0	90
07.4	14.8	22.2	29.6	37.0	44.4	51.8	59.2	66.6	74.0	81.4	88.8	96.2	400.0

TABLE 162.—*Concluded*

41	42	43	44	45	46	47	48	49	50	75	100		D'uble Areas
57.7	59.2	60.6	61.9	63.4	64.8	66.2	67.6	69.0	70.4	105.7	140.7	—	76.0
9.2	60.7	2.1	3.6	5.0	6.4	7.8	9.3	70.7	2.3	08.4	44.4	—	8.0
60.8	2.2	3.7	5.2	6.7	8.2	9.7	71.2	2.6	4.1	11.2	48.1	—	80.0
2.2	3.8	5.3	6.8	8.3	9.8	71.4	2.9	4.4	5.9	14.0	51.8	—	2
3.8	5.4	6.9	8.4	70.0	71.6	3.2	4.7	6.2	7.8	16.8	55.5	—	4
65.3	66.8	68.4	70.1	71.7	73.3	74.8	76.4	78.0	79.6	119.5	159.2	—	6
6.8	8.4	70.1	1.7	3.4	5.0	6.6	8.3	9.8	81.5	22.3	63.0	—	8
8.4	70.0	1.7	3.3	5.0	6.7	8.4	80.0	81.7	3.4	25.1	66.7	—	90.0
9.8	1.6	3.3	4.9	6.7	8.4	80.1	1.8	3.5	5.2	27.9	70.6	—	2
71.4	3.2	4.8	6.6	8.4	80.2	1.9	3.6	5.3	7.1	30.7	74.1	—	4
72.8	74.7	76.4	78.2	80.0	81.8	83.6	85.3	97.1	88.9	133.4	177.7	—	6
4.4	6.3	8.1	9.9	1.7	3.5	5.3	7.2	8.9	90.8	36.2	81.6	—	8
5.9	7.7	9.7	81.4	3.3	5.2	7.0	8.8	90.7	2.6	38.9	85.1	—	100.0
9.8	81.7	83.6	5.6	7.5	9.4	91.4	93.4	95.3	7.2	45.9	94.4	—	05
83.5	5.6	7.6	9.6	91.7	93.7	5.7	7.8	9.8	101.9	52.8	203.7	—	10
87.3	89.4	91.6	93.7	95.8	97.9	100.1	102.2	104.4	106.5	159.8	212.9	—	15
91.2	93.4	5.6	7.8	100.0	102.2	04.5	06.7	08.9	11.8	66.7	22.2	—	20
5.0	7.3	9.7	101.9	04.2	06.5	08.9	11.2	13.5	15.6	73.7	31.4	—	125.0
8.8	101.2	103.6	05.9	08.4	10.7	13.1	15.5	17.9	20.2	80.5	40.7	—	30
102.5	05.0	07.5	10.0	12.5	15.0	17.5	20.0	22.5	25.0	87.5	50.0	—	35
106.3	108.9	111.5	114.2	116.7	119.3	121.9	124.4	127.1	129.8	194.5	259.2	—	40
11.2	12.9	15.5	18.2	20.8	23.6	26.2	28.9	31.7	34.3	201.5	68.5	—	45
14.0	16.7	19.5	22.3	25.0	27.8	30.6	33.4	36.2	38.9	08.5	77.7	—	150.0
17.8	20.6	23.5	26.3	29.2	32.1	34.9	37.8	40.8	43.6	15.4	87.0	—	55
21.5	24.5	27.4	30.4	33.4	36.4	39.4	42.3	45.2	48.2	22.4	96.3	—	60
25.3	128.4	131.5	134.4	137.6	140.6	143.8	146.8	149.8	152.8	229.3	305.5	—	65
129.1	32.3	35.4	38.5	41.7	44.9	48.0	51.2	54.3	57.4	36.2	14.8	—	70
32.9	36.1	39.4	42.5	45.8	49.0	52.2	55.5	58.8	62.0	43.0	24.0	—	175.0
36.8	40.0	43.4	46.8	50.0	53.4	56.8	60.0	63.4	66.8	50.0	33.3	—	80
40.5	43.9	47.4	50.8	54.2	57.7	61.0	64.5	67.9	71.4	56.9	42.6	—	85
144.4	147.8	151.4	154.9	158.4	161.9	165.4	168.9	172.4	176.0	263.9	351.8	—	90
48.1	51.8	55.3	58.9	62.5	66.2	69.8	73.4	77.0	80.5	70.8	61.1	—	95
51.8	55.6	59.3	63.0	66.8	70.4	74.1	77.8	81.4	85.2	77.7	70.3	—	200.0
59.5	63.4	67.3	71.1	75.0	78.9	82.8	86.7	90.5	94.5	91.6	88.9	—	10
67.0	71.2	75.2	79.3	83.4	87.5	91.5	95.6	99.7	203.7	305.5	407.4	—	20
174.7	178.9	183.3	187.5	191.8	196.0	200.1	204.4	208.8	213.0	319.4	425.9	—	30
82.2	86.8	91.1	95.5	200.0	204.5	08.8	13.3	17.8	22.2	33.3	44.4	—	40
89.8	94.5	99.0	203.7	08.3	13.0	17.5	22.2	26.8	31.5	47.1	62.9	—	250.0
97.4	202.3	207.0	11.9	16.6	21.6	26.3	31.1	36.0	40.8	61.0	81.5	—	60
205.0	10.0	15.0	20.0	25.0	230.0	35.0	40.0	45.0	50.0	75.0	500.0	—	70
212.7	217.8	223.0	228.2	233.3	238.6	243.7	248.9	254.1	259.2	388.7	518.5	—	80
20.2	25.6	30.9	36.3	41.7	47.1	52.4	57.8	63.2	68.5	402.7	37.0	—	90
27.8	33.4	38.9	44.5	50.0	55.6	61.1	66.7	72.3	77.8	16.5	55.5	—	300.0
35.4	41.2	46.9	52.6	58.3	64.2	69.8	75.6	81.3	87.0	30.4	74.0	—	10
43.0	49.0	54.8	60.8	66.7	72.7	78.5	84.4	90.4	96.3	44.3	92.6	—	20
250.6	256.7	262.8	268.9	275.0	281.2	287.2	293.3	299.5	305.5	458.2	611.0	—	30
58.2	64.5	70.7	77.1	83.3	89.7	95.9	302.2	308.5	14.8	72.1	29.6	—	40
65.7	72.3	78.7	85.2	91.7	98.2	304.6	11.1	17.6	24.1	85.9	48.1	—	350.0
73.3	80.1	86.7	93.4	300.0	306.8	13.3	20.0	26.7	33.0	99.8	66.0	—	60
80.9	87.9	94.6	301.5	08.3	15.3	22.0	28.9	35.8	42.6	513.7	85.2	—	70
288.5	295.6	302.6	309.7	316.7	323.8	330.7	337.8	344.8	351.8	527.6	703.6	—	80
96.1	303.4	10.5	17.8	20.0	32.3	339.4	46.7	53.9	61.1	41.5	22.2	—	90
303.7	11.1	18.5	25.9	33.3	40.7	48.1	55.5	62.9	70.3	55.5	40.6	—	400.0

TABLE 163.—CONVERSION TABLE, LINEAL FEET TO MILES

1 to 9		10–90		100–900		1000–9000		10,000–90,000	
Feet	Miles	Feet	Miles	Feet	Miles	Feet	Miles	Feet	Miles
1	0.00019	10	0.00189	100	0.01894	1000	0.18939	10,000	1.8939
2	0.00038	20	0.00379	200	0.03788	2000	0.37879	20,000	3.7879
3	0.00057	30	0.00568	300	0.05682	3000	0.56818	30,000	5.6818
4	0.00076	40	0.00758	400	0.07576	4000	0.75758	40,000	7.5758
5	0.00095	50	0.00947	500	0.09470	5000	0.94697	50,000	9.4697
6	0.00114	60	0.01136	600	0.11364	6000	1.13636	60,000	11.3636
7	0.00132	70	0.01326	700	0.13258	7000	1.32576	70,000	13.2576
8	0.00152	80	0.01515	800	0.15152	8000	1.51515	80,000	15.1515
9	0.00171	90	0.01705	900	0.17046	9000	1.70455	90,000	17.0455

Shrinkage of Earthwork.—No mention has been made of the hrinkage of earth cut when placed in fill. This is an important actor of an economical grading design.

Trautwine states that for railroad work it takes 1.08 cu. yd. of ravel or sand excavation, 1.10 cu. yd. of clay excavation, 1.12 cu. d. of loam excavation, and 1.15 cu. yd. of vegetable surface soil xcavation to make 1 cu. yd. of embankment.

The quantities 1.08 cu. yd. of gravel, etc., refer to the volume ccupied by the material before removal.

Trautwine also states that in loosening earth and loading into vagons or cars 1 cu. yd. of earth swells about one-fifth and measures oose practically 1.2 cu. yd.

These values, however, cannot be used in road work, as a certain ercentage of the excavation is sod or vegetable matter that is not uitable for embankment and must be wasted.

This waste material raises the percentage of cut necessary to nake the fill.

The correct ratio for road work has been a source of contention mong engineers, and it is believed that the use of too high a value as resulted in needless waste of thousands of dollars during the ast 5 years in New York State alone.

Under this head it may be stated that on several roads under he supervision of W. G. Harger a careful study of this point was nade, unusual care being taken with the original and final cross-ections, the plotting, and planimeter work, and it was found that or the cases investigated the ratio of cut to fill varied from 1.15 n heavy cuts to 1.27 in light skimming work.

It is the general opinion among engineers of Division 4, New York State Department of Highways, that the percentage formerly used (namely 1.35) is too high. In nearly all cases where the work was at all heavy a large excess of dirt had to be wasted. There have been some roads designed on a basis of 1.35 where more dirt was needed, but in the authors' opinions this was due to discrepancies in the field or office work or by allowing the contractor to use the roadbed excavation for filler or concrete material. If the soil encountered is suitable for such purposes, it is plainly up to the contractor to furnish other material for the places excavated.

The authors believe that the following ratios will be satisfactory for ordinary cases: Earth excavation where sod is rejected for fill.

TABLE 164

	Cubic Yards per Station	Ratio Excavation to Compacted Fill
Light skimming work, large amount of heavy sod	50	1.35
Light skimming work, considerable sod	60	1.30
Light skimming work, not much sod	60	1.25
Medium work	100	1.20
Heavy work	150–200	1.15

Trautwine's earth ratios are correct where earth borrow obtained from a pit.

Trautwine states that 1.0 cu. yd. of solid rock, when broken u will make 1.66 to 1.75 cu. yd. of rock fill.

In this statement he assumes that the fill is made of stone alo and that the voids are not filled. In most road work, the sma quantities of rock encountered are dumped in with the earth embankment, and as the voids are all filled with earth it is evide that 1 cu. yd. of rock will make only 1 cu. yd. of fill; however, a large unmixed stone fill is made, his ratio holds.

In shale rock excavation, 1 cu. yd. will make from 1 to 1.2 cu. y of compacted fill, depending on its hardness and how it is excavate that is, whether it comes out in large blocks or is considerab pulverized.

The discussion of these ratios has been carried out to some lengt because it is believed that they illustrate the advantage of caref engineering. Several of the New York State plans, the cost which has ranged from $100 to $200 per mile, have been revise with this end in view, the revision costing an additional $15 to $ per mile, with a resultant saving in construction cost of from $4 to $1000 per mile.[1]

The use of a rolling grade was recommended in the chapter c Grades. The designer is cautioned, however, not to carry this extremes, as there are many short, small hummocks which must disregarded if a reasonably good profile is to be obtained. Figu 313 (p. 963) indicates a proper and improper use of an undulatin grade.

Figure 313*A* illustrates the actual profile on Road 5046 New Yo State for a short, sharp roll which has proved entirely satisfacto for traffic but which is about the limit of permissible abruptness.

Overhaul.—If dirt must be hauled more than a stated distan (free haul) to place it in fill, the additional distance over th free haul length is called overhaul and is paid for at an agreed pric The amount of overhaul is usually estimated as Sta. yd., meanin the number of cubic yards of excavation that have to be overhaule multiplied by the length of the overhaul expressed in stations c 100′ each; that is, if 20 cu. yd. of excavation have to be haule 1500′ (15 stations) to place in fill and the free haul is stipulate as 1000′, overhaul would be computed as

$$20 \text{ cu. yd.} \times (15 \text{ Sta.} - 10 \text{ Sta.}) = 100 \text{ sta. yd.}$$

If the cut from which the dirt is excavated is short and we defined and the fill likewise well defined the overhaul can b figured with reasonable accuracy by taking the distance from th center of gravity of the cut to the center of gravity of the fill whic can be easily located by inspection. If, however, the cuts and fill are not well defined and the cut from two or three locations i hauled to a number of fills it is necessary to adopt a standar method of computing haul. Also, due to the methods of makin fills it is generally impossible to determine exactly the distanc actually hauled by the contractor and the usual basis of measurin

[1] 1912 scale of costs.

overhaul is the mass-diagram method, which assumes that each yard of earth is hauled the minimum theoretical distance to place it in the fill.

Mass Diagram.—The mass diagram merely represents graphically the location and amount of each cut and its direction and length of haul to place it in fill. Vertical ordinates on the diagram represent cut or fill, cut being plotted upward and fill downward. Fills must be converted into equivalent excavation before being plotted. Distance is represented by the horizontal dimensions.

The steps in determining overhaul from mass diagrams are as follows:

1. Compute total excavation and embankment for the roadway and all borrow pits.
2. Determine ratio between total excavation and total embankment.
3. Convert embankment into equivalent excavation, using ratio just determined.
4. Compile mass-diagram tabulation station by station for both roadway and borrow pits
5. Plot mass diagram.
6. Divide mass diagram into a series of sections where cut balances fill.
7. Eliminate free haul from each of these balances.
8. Compute overhaul from remaining area of diagram.

Figures 318, 319, and 320 illustrate three typical cases and are explained as follows.

Case I. Earth from a Well-defined Borrow Pit, the Center of Which Is Located by Inspection at Sta. 0, Is Used in Making a Fill Extending from Stas. 0 to 10. Free Haul Specified as 500′.—The first step is to compute from the cross-sections the total excavation in the borrow pit and the fill quantities station by station. This is shown in columns 1 to 4, Table 165, to be 1520-cu. yd. excavation and 1384 cu. yd. fill in place. The ratio of cut to fill, for example, in question is 1.10. The embankment quantities must next be changed to equivalent excavation, as the overhaul is figured in terms of excavation yardage. This is done by multiplying each embankment quantity in column 4 by the factor 1.10 and recording the results in column 5. If correctly done the total of column 5 should equal the total of column 3, although, due to the factor ratio not being exact, a slight difference not totaling over 1% is of no practical consequence. The next step is to fill in columns 6 and 7, which represent the net excess of excavation or fill for each station figured and are the differences between columns 3 and 5. This net excess represents the quantity of material that must be moved by haulage. For this case with simple cuts and fills the totals of columns 6 and 7 should agree and be the same as for columns 3 and 5. The next step is to compute the algebraic total to each station as shown in column 8, considering excess excavation, column 6, as a plus quantity and excess embankment, column 7, as a minus quantity. The last quantity in column 8 should be zero, although a variation of less than 1% of the total is allowable—in this particular tabulation one-fifth of 1%.

TABLE 165.—MASS-DIAGRAM COMPUTATIONS, CASE I

Station to station		Excavation, cubic yards	Embankment, cubic yards	Embankment converted to equivalent excavation	Excess per station		Algebraic total
					Excavation	Embankment	
(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)
0	Borrow pit	1520	....	....	1520	....	+ 1520
0	1	....	108	119	....	119	+ 1401
1	2	....	200	220	....	220	+ 1181
2	3	....	151	166	....	166	+ 1015
3	4	....	175	193	....	193	+ 822
4	5	....	60	66	....	66	+ 756
5	6	....	40	44	....	44	+ 712
6	7	....	30	33	....	33	+ 679
7	8	....	170	187	....	187	+ 492
8	9	....	250	275	....	275	+ 217
9	10	....	200	220	....	220	− 3
Totals....................		1520	1384	1523	1520	1523	

Ratio cut to fill, 1.10.

The mass diagram is plotted from the data in column 8, using any convenient scale (see Fig. 318). It can be readily seen that the area *ATBCDEFSA* represents the total yardage excavated multiplied by the distance each yard is hauled or the total station yards hauled, as a yard of dirt at *A* is not hauled at all. A yard at *S* is hauled to *T*, a yard at *F* to *B*, and a yard at *E* to *C*, etc., the sum of which strips equals the total area. To get the overhaul, take out the free haul of 500′ (vertical line at Sta. 5) and the overhaul is the area *BCD*. This area is 2.34 sq. in. and the overhaul for the scales used (1000 sta. yds. per sq. inch) is 2.34 sq. in. × 1000 = 2340 sta. yd.

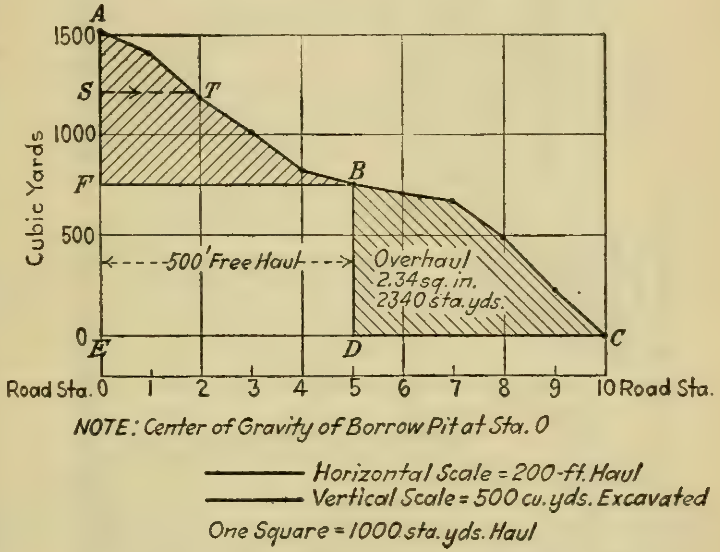


FIG. 318.—Mass diagram, Case I.

Scales 1″ = 500 cu. yd. excavated, vertical
1″ = 200′ haul, horizontal
1 sq. in. = 1000 sta. yd. haul

Case II. Road in Part Cut Well Defined and Part Fill for Some of the Distance, Full Cut and Full Fill for Other Sections and a Well-defined Borrow Pit, the Center of Gravity of Which Is 500′ off the Middle of the Road. Free Haul 400′.—Procedure is the same in the matter of tabulation of quantities as Case I (see Table 166). The mass diagram is shown in Fig. 319 and is explained as follows: Two diagrams must be used on account of dead haul from the borrow pit. The cut from Stas. 0 to 2 makes the fill from Stas. 2 to 3 + 30 where the fill line cuts the datum line at *C*. As the distance *AC* is less than 400′ (free haul), there is no overhaul, Stas. 0 to 3 + 30.

The fill from Stas. 3 + 30 to 5 is obtained from the borrow pit located 500′ off the road *DF*. As the free haul is 400′, the line *EH* represents the limit of free haul and the area *CHEDG* represents the overhaul on the fill from Stas. 3 + 30 to 5. This area equals 0.6

TABLE 166.—MASS-DIAGRAM COMPUTATIONS, CASE II

Station to station		Excavation, cubic yards	Embankment, cubic yards	Embankment converted to equivalent excavation, cubic yards	Excess per station		Algebraic total, cubic yards
					Excavation	Embankment	
(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)
0	1	+ 200	......	......	+ 200	......	+200
1	2	+ 50	− 10	− 11	+ 39	......	+239
2	3	......	− 50	− 57	......	− 57	+182
3	4	......	− 500	− 569	......	− 569	−387
4	5	......	− 300	− 342	......	− 342	−729
Borrow west Sta.	5	+1,305	......	......	+ 1305	......	+576
5	6	......	− 200	− 228	......	− 228	+348
6	7	+ 50	− 50	− 57	......	− 7	+341
7	8	+ 60	− 10	− 11	+ 49	......	+390
8	9	+ 30	− 30	− 34	......	− 4	+386
9	10	+ 25	− 60	− 68	......	− 43	+343
10	11	......	− 110	− 125	......	− 125	+218
11	12	......	− 190	− 217	......	− 217	+ 1
Totals..................		+1720	−1510	−1719	+1593	−1592	

Ratio cut to fill, 1.14.

NOTE.—Columns 6 and 7 quantities are obtained by subtracting column 5 quantities for each station from column 3 quantities for the same station.

sq. in. × 2500 sta. yds. per sq. inch = 1500 sta. yd. overhaul, Stas. 0 to 5.

In a similar way from Stas. 5 to 12 there is a small distance, Stas. 7 to 10, where the cut makes the fill (area *MNO*). For the balance of the distance overhaul is required from the borrow pit. The limit of free haul from the pit is marked by the line *KQ* and the overhaul is measured by the area *KLMOPQK*, which equals 1.08 sq. in. × 2500 sta. yd. per square inch = 2700 total sta. yd. overhaul, Stas. 5 to 12.

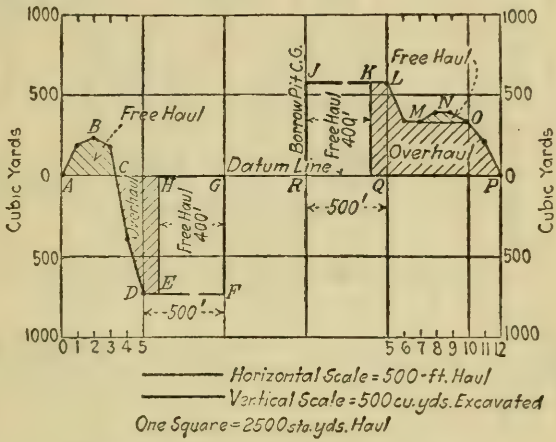


FIG. 319.—Mass diagram, Case II.

Scales 1″ = 500 cu. yd. excavated, vertical
1″ = 500′ haul, horizontal
1 sq. in. = 2500 sta. yd. haul

Case III. Borrow Obtained from a Long Variable Section Pit and Placed in a Long Section of Road Fill with a Long Intermediate Section of Road Where the Cut Makes the Fill. Free Haul 400′.—For a borrow pit of the kind it is necessary to compute and plot the pit in the same manner used for the roadway computations. These computations are made in the direction of haul in the pit; that is, the zero cut quantity is taken at the point in the pit farthest from the road. The tabulation of quantities for this case is given as follows:

Figure 320 shows the completed diagram for Case 3. It is explained as follows. Line *ABCDEFGHJ* is plotted from the tabulation of quantities. The next step is to determine and eliminate from the diagram any sections of the road where the cut makes the fill with a haul of less than 400′ free haul. Bearing in mind that cut is plotted up and fill down, it is evident that roadway excavation *DF* makes the fill line *FH* and no borrow-pit material is required from *D* to *H* (Stas. 3 to 9+70). Bearing in mind that the horizontal line *DH* represents the length of haul for a yard excavated at *D* and placed at *H*, which is 670′ and that the free haul is only 400′, it is evident that between Stas. 3 and 9+70 some of the roadway excavation must be overhauled. A horizontal line *EG* is therefore drawn, locating it by shifting up, so that it is exactly 400′ long (free haul

TABLE 167.—MASS-DIAGRAM COMPUTATION, CASE III

Station to station		Excavation, cubic yards	Embankment, cubic yards	Embankment converted to equivalent excavation, cubic yards	Excess per station		Algebraic total
					Excavation	Embankment	
(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)
Borrow pit							
0B	1B	800	....	....	+ 800	......	+ 800
1B	2B	900	....	....	+ 900	......	+1700
2B	3B	150	....	....	+ 150	......	+1850
3B	4B	85	....	....	+ 85	......	+1935
4B	5B	1353	....	....	+1353	......	+3288
Distance Sta. 5B to Sta. 0 of road is 800′							
Roadway	0	....	....	....	......	......	+3288
0	1	....	100	112	......	− 112	+3176
1	2	....	120	134	......	− 134	+3042
2	3	30	30	34	......	− 4	+3038
3	4	150	....	....	+ 150	......	+3188
4	5	200	....	....	+ 200	......	+3388
5	6	172	....	....	+ 172	......	+3560
6	7	150	....	....	+ 150	......	+3710
7	8	10	40	45	......	− 35	+3675
8	9	....	200	224	......	− 224	+3451
9	10	....	500	559	......	− 559	+2892
10	11	....	830	928	......	− 928	+1964
11	12	....	1250	1399	......	−1399	+ 565
12	13	....	500	559	......	− 559	+ 6
Totals..................		4000	3570	3994	+3960	−3954	

Ratio cut to fill, 1.12.

distance), where it cuts the diagram line. This means that the roadway excavation from E (Sta. 5) to F (Sta. 7) just makes the fill from F, Sta. 5, to G, Sta. 9, without any overhaul. To get the overhaul on excavation from D, Sta. 3, to H, Sta. 9+70, take out the free-haul area $EGTS$ and the overhaul is given by the sum of the areas DES and GHT.

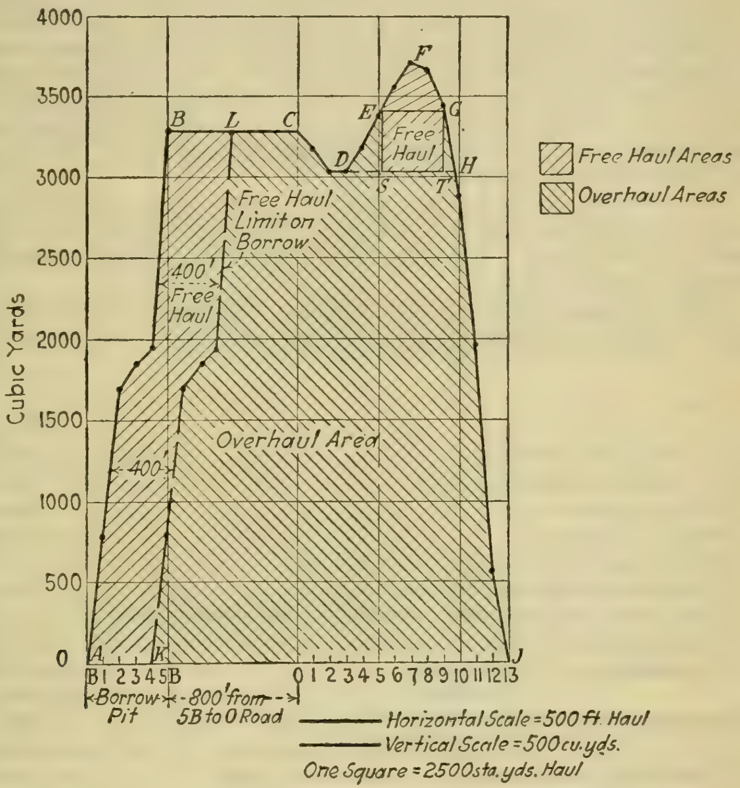


FIG. 320.—Mass diagram, Case III.

Scales 1″ = 500 cu. yd., vertical
1″ = 500′ haul, horizontal
1 sq. in. = 2500 sta. yd. of haul

The next step is to take out the free haul from the borrow-pit haul which is accomplished by drawing the line KL parallel to AB and 400′ away from it. The overhaul on the borrow-pit excavation is then the area $KLCDHJK$.

The total overhaul for Case 3 is area $KLCDESTGHJK$, which equals 22.7 sq. in. multiplied by 2500 sta. yd. per square inch = 56,700 sta. yd.

These three cases outline the general principle of the work and if the fundamentals have been grasped minor modifications in conditions will give no trouble.

Structures.—This book is not intended as a textbook of structural design (culverts, bridges, etc.). Most cases can be handled by the use of standard designs for small-span bridges given in Chap. IV, (pp. 214 to 310) or by the use of the state or federal standards applicable to the locality in question. Basic data for types of structures, waterway areas, etc., are given in Chap. IV, Drainage, Part I. The following tables and basic design data will, however, be useful for cases where special designs are required or where it is necessary to figure the safe load of existing structures for repair or condemnation purposes, provided the reader is familiar with design methods. If the reader is not familiar with design methods he is referred to Ketchum's "Highway Bridges," for culvert, bridge, and retaining-wall design, and to "Concrete Engineer's Handbook," by Hool and Johnson for concrete arch design.

The cost of surveys, designs, final plans, and estimates for small-span bridges of less than 45′ span will range from $\frac{2}{3}$ to 2% of the cost of the structure. This cost permits proper economic alternate design investigations.

Bridge Designs.—The steps of ordinary small-span bridge design with references in regard to location of required data are as follows:

		Pages
Channel straightening		181
Location of structure		181
Waterway area		186
Débris clearance		186
Possible utilization of parts of old structure		210
Economical type of structure		205
Final road surface grade considering high-water débris, clearance, and depth of floor system		1025
Foundation and abutments		207
Superstructures	Loading	200
	Roadway widths	203
	Standard details	214–310
Protection from scour		211
Cost estimates		1150

A design report should be prepared discussing alternate possibilities for each part of the design and giving the reason for the adopted design (see p. 774).

In training designers the author has been in the habit of starting out by telling them that there are a number of satisfactory ways of solving any problem and that their designs would be accepted without requests for revision, provided they mastered the broad general principles outlined in Chap. IV and actually used their brains to get a reasonably suitable and economical design. Designs are never accepted merely because they comply with standards, but any reasonable design is accepted which shows careful analysis and an effort to produce an economical structure suitable to local conditions.

GENERAL STATEMENT OF DESIRABLE ECONOMIC TYPES OF SUPERSTRUCTURES (SMALL SPAN)

Div. No. 4, N. Y. S. Div. of Highways

Spans 5 to 25′.—Slab type of bridge prefered for all ordinary foundation conditions. For soft foundations requiring piles I beam stringer type generally preferable on account of difficulty of forming (liability of settlement of deck bents). In case slab type used on soft foundations forms must be supported on piles or framed trusses supported by abutment toe. On hard foundations use rigid frame type of slab.

Spans 25 to 45′.—Hard pan or rock foundations with excessive headroom creek to road grade use reinforced concrete arches or I beams.

Hard pan or rock foundations at low stream crossings use double span slabs with pier where there is no danger of stream clogging. Use T beam superstructures or I beam superstructures where single spans are required. The use of T beams or I beams depending on cost considering the effect of difference in depth of floor for the two types on approach costs as well as the comparative cost of the superstructures.

For ordinary foundation soils it is rarely advisable to use piers for spans less than 45 feet. For these conditions use T beam or I beam structures the selection depending on economic costs considering effect of depth of floor on approach costs as well as cost of bridge proper. If piers are used on ordinary soil foundations each span should be designed with free ends. Felt construction joints are advisable to permit minor settlement without crushing or cracking of parapets. Pipe rail parapets are to be preferred to solid concrete for this condition. On hard pan or rock foundations the continuous beam design is desirable making reinforcement continuous with no provision for expansion or contraction up to 50′ total length of multiple spans.

Spans 45 to 100′.—Multiple or single spans as determined by economy of design and suitability of piers. Piers to be spaced not closer than 4 times range of depth between high and low water. Arches preferred on rock or hard pan foundations. T beams next choice. On the soft foundations I beams stringers or plate girders.

Loading.—Use H-15 for roads carrying less than 2000 vehicles daily (10 hour count in summer). Use H-20 for roads over 2000 vehicles, allowing for 60 year traffic increase.

GENERAL BASIS OF DESIGN

State Road Bridge Widths & Pedestrian Traffic

(Division No. 4 New York State 1927)

Allow for 30 years traffic increase on types of bridges that can be widened without entire rebuilding (slabs, T beams, stringers & arches) class A bridges.

Allow for 60 years traffic increase for trusses and plate girders (class B bridges).

The following satisfactory bridge widths for different volumes of traffic are based on 12 hour traffic counts in August. Allow 70% increase for 30 years and 100% increase for 60 years for roads on portions of the system which are completed and traffic routes fixed. Make special increases or decreases for future adjacent improved roads which will radically change normal increase which is based on population increase (see future traffic chart for Division No. 4, page 31).

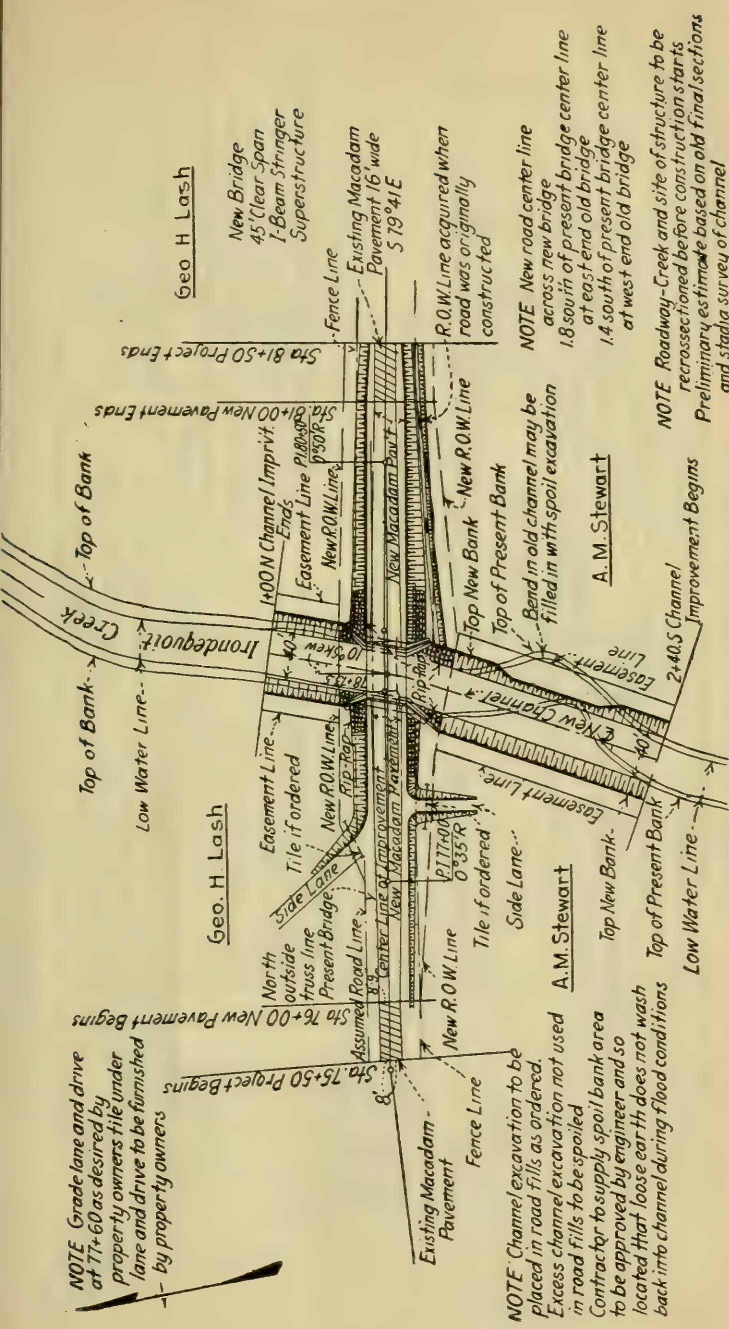
Maximum future traffic volume (12 hr. count in August) allow for 30 to 60 years increase	Recommended roadway width			
	Class A bridges			Class B bridges over 45′ span
	10′–25′ span	25′–45′ span	Over 45′ span	
Class I AA, over 9000 vehicles....	40′	40′	40′	40′
Class IA, 5000–9000 vehicles......	40′	40′	30′	30′
Class I, 2000–5000 vehicles........	30′	30′	24′	24′
Class II, 1000–2000 vehicles.......	30′	24′	22′	22′
Class III, 300–1000 vehicles.......	30′	24′	22′	22′
Class IV, under 300 vehicles.....	24′	22′	20′	20′

Pedestrian Traffic

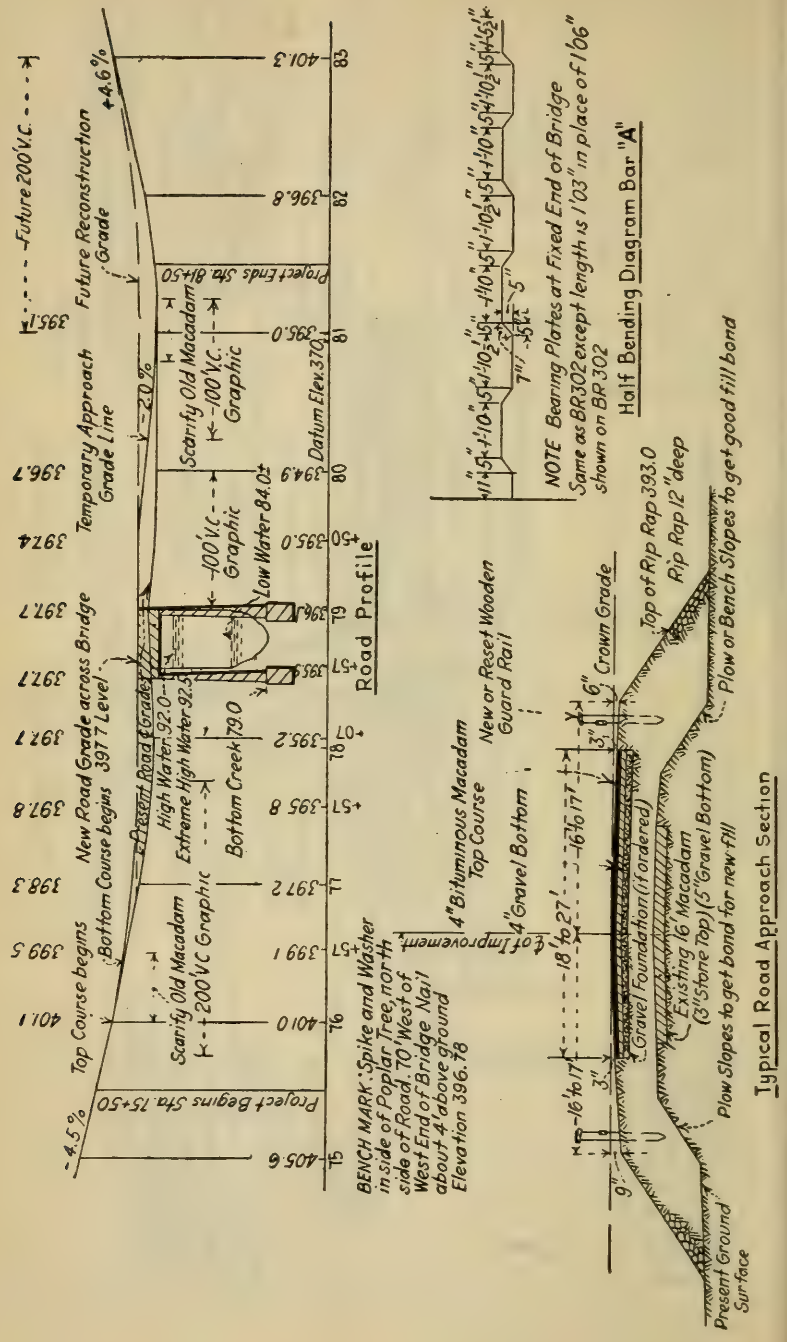
Where there is immediate necessity for sidewalks use either separate foot bridge or walks on bridge are required by the layout to fit local conditions. Where there is no immediate necessity for walks on the bridge make no special provision on Class A bridges as these bridges can either be widened or separate foot bridges near the road lines can be easily provided in the future for spans under 45 feet. Where class B bridges are used provide connections for future sidewalk brackets as it is practically certain that within a few years sidepaths for pedestrians will be common practice on State Roads.

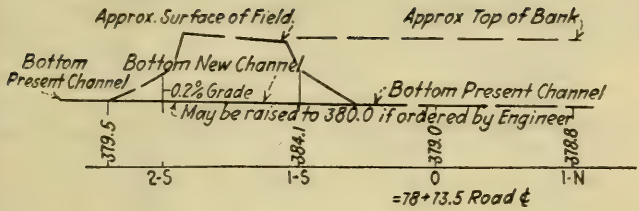
Signed........................
Bridge Eng.

Bridge Plans (see pp. 1007 to 1012).—Bridge plans should include a general layout showing location of structure, channel improvements, road approaches, etc., a set of detail sheets carefully dimensioned and elevationed to give all necessary construction data, and sheets giving the estimate of quantities, bill of materials, detail bar lists, and bending diagrams. The size of sheet is the same as for road plans. Scales for general layout are generally 50′ to the inch horizontal and 10′ to the inch vertical. Scales for details are varied to bring out the necessary data, and generally range from ¼ to 1″ per foot. For small simple structures where the regular road cross-sections are plotted 1″ to 5′ it is just as well to retain this same scale, as it corresponds with the road plan cross-sections.

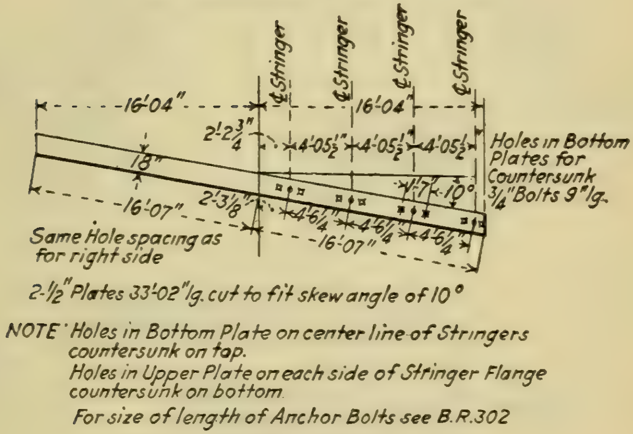


Typical plans (1). General layout.


Future 200'V.C.
Future Reconstruction Grade
Temporary Approach Grade Line
New Road Grade across Bridge
Bottom Course begins 397.7 Level
Top Course begins
Bottom Course begins
+4.6%
-4.5%
-2.0%
Project Begins Sta. 75+50
Project Ends Sta. 81+50
Scarify Old Macadam
200'VC Graphic
100'V.C. Graphic
Present Road ℄ Grades
High Water 92.0
Extreme High Water 92.5
Bottom Creek 79.0
Low Water 84.0
Datum Elev. 370
401.1
399.5
398.3
397.8
397.7
397.7
397.7
397.4
396.7
395.1
405.6
401.0
399.1
397.2
395.8
395.2
395.0
394.9
395.0
396.8
401.3
Road Profile
BENCH MARK: Spike and Washer in side of Poplar Tree, north side of Road, 70' West of West End of Bridge Nail about 4' above ground Elevation 396.78
NOTE Bearing Plates at Fixed End of Bridge Same as BR302 except length is 1'03" in place of 1'06" shown on BR 302
Half Bending Diagram Bar "A"
4" Bituminous Macadam Top Course
4" Gravel Bottom
New or Reset Wooden Guard Rail
℄ of Improvement
Crown Grade
Top of Rip Rap 393.0
Rip Rap 12" deep
Gravel Foundation (if ordered)
Existing 16' Macadam (3" Stone Top) (5" Gravel Bottom)
Plow Slopes to get bond for new fill
Plow or Bench Slopes to get good fill bond
Present Ground Surface
Typical Road Approach Section

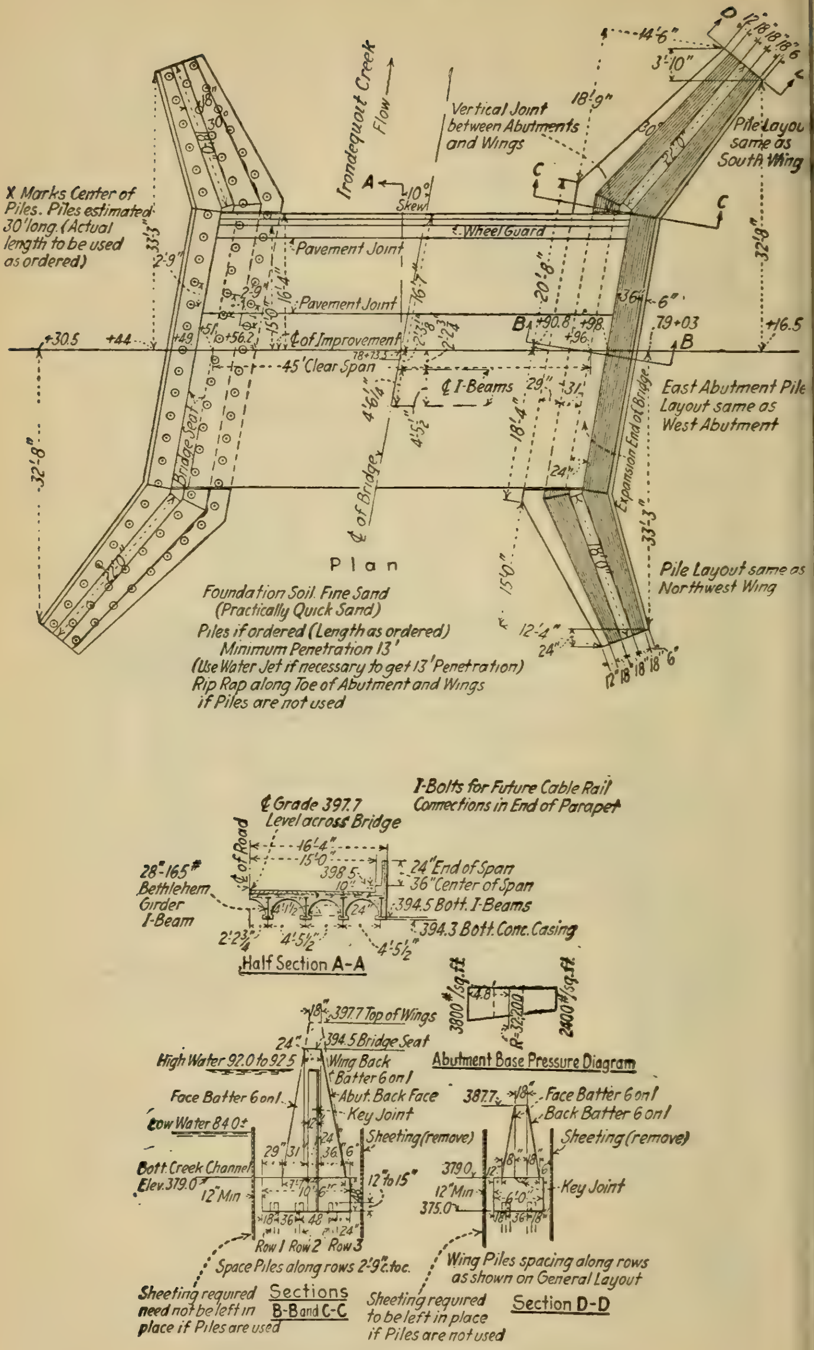


New Channel Profile



Expansion Plate Details

Typical plans (3). Creek profile and expansion plate.



Typical plans (4). Bridge details.

General Notes

General clauses B.R. 302 & 702 to apply.
All concrete rub finished.
Earth excavation maximum limit of payment as per B.R. 702.
PECIAL FORM NOTE
Abutment and wing forms shall have the following minimum quirements.
Face forms 1½″ tongue and grooved lumber plained on one side.
Vertical studding at least 2″ × 6″ spaced not over 24″.
Horizontal studding at least 4″ × 6″ spaced not over 24″.
Forms tied with rods. Wire ties not permitted.
Tie rods spaced not more than 42″ along whailers.
Studs spaced 16″ c. to c. for ⅞″ facing.
Wire ties 2—No. 6 or 4—No. 9 spaced 36″ along wales.

PRELIM. SUMMARIZED ESTIMATE

No.	Item	Unit	Net	Cont.	Gross
1	Clearing and grubbing........	L. S.	Nec.	....	Nec.
2	Earth excavation.............	C. Y.	4,000	500	4,500
3	Rock excavation.............	C. Y.	....	10	10
7b	4″ Pipe underdrain...........	lin. ft.	....	100	100
10	Relaying pipe................	lin. ft.	....	100	100
15	Portland cement..............	bbl.	950	150	1,100
16	Cement concrete for structures	C. Y.	95	5	100
17	Cement concrete for parapets..	C. Y.	6.1	0.9	7
21	2nd clase concrete............	C. Y.	580	60	640
30	Metal reinforcement for pavement......................	sq. yd.	151	9	160
30A	Bar reinforcement for structures......................	lbs.	6,200	300	6,500
32B	Structural steel..............	lbs.	66,430	570	67,000
34	Wooden guide rail............	lin. ft.	100	200	300
38	Preparing fine grade..........	sq. yd.	1,050	50	1,100
39	Foundation course (run of bank gravel)......................	C. Y.	....	150	150
42	Bottom course (run of bank gravel)......................	C. Y.	100	20	130
47	Top course bituminous macadam......................	C. Y.	120	10	130
51D	Cement concrete pavement....	C. Y.	14	1	15
56	Trimming shoulders..........	lin. ft. rd.	500	50	550
59	Scarifying old macadam.......	sq. yd.	....	100	100
60A	Bituminous material waterproofing..................	sq. yd.	1,350	50	1,400
62	Screened gravel (loose measure)	C. Y.	....	50	50
72	Bituminous material T penetration......................	gal.	3,300	200	3,500
78	Maintaining traffic (if ordered)	L. S.	....	Nec.	Nec.
80	Rip rap......................	C. Y.	150	10	160
82	Dismantling superstructure and steel abut................	L. S.	Nec.	....	Nec.
83	Coffer dams, etc.............	L. S.	Nec.	....	Nec.
84	Timber piles.................	lin. ft.	....	4,000	4,000
87	Test piles...................	each	2	2	4
89	Resetting wooden guide rail...	lin. ft.	600	100	700

Typical Plans (5). General notes and summarized estimate.

Approx. Bill of Materials

Item	Net est.	Gross est.
Cement	950 bbl. ±	1,100 bbl. ±
Concrete stone	700 C. Y. ±	760 C. Y. ±
Concrete sand	350 C. Y. ±	380 C. Y. ±
Rip rip stone	150 C. Y.	160 C. Y.
4″ Drain tile if ordered	....	100 lin. ft.
Screened drain gravel if ordered	....	50 C. Y.
Steel (see special list)		

Detail Bar List

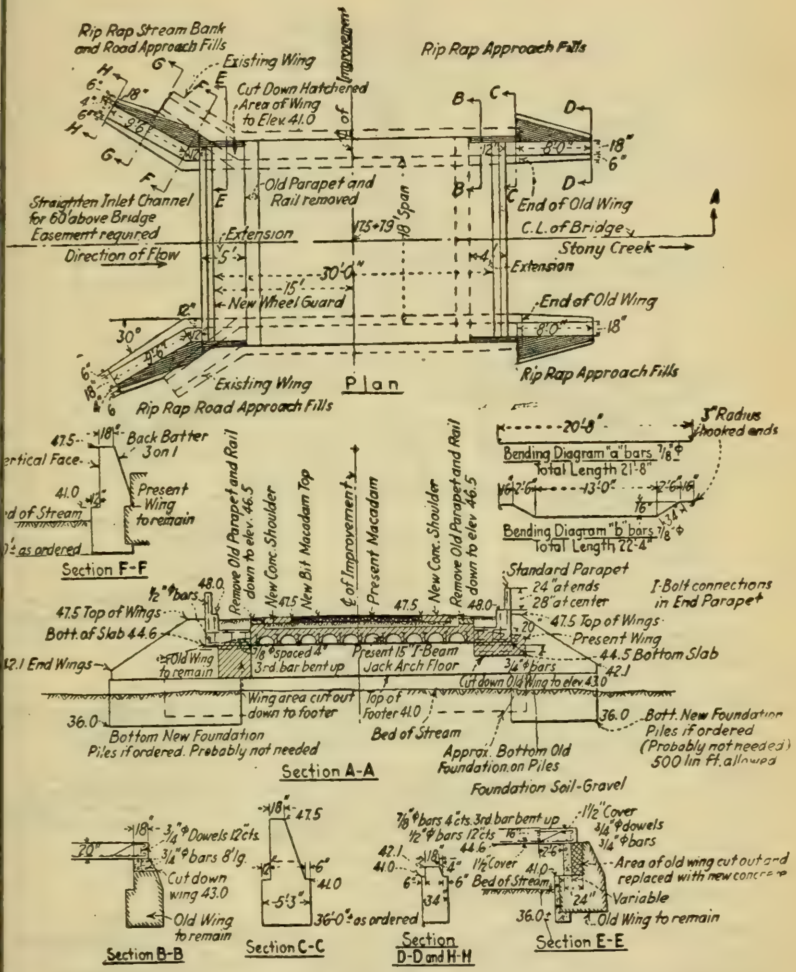
Bar designation (see BR 302)	Size of bar	Number of bars	Length each bar	Location of bars
a	½″φ	69	35′–02″	Bent traverse slab bar
b	½″φ	136	32′–10″	Straight traverse slab bar
c	½″φ	8	48′–08″	Straight longitudinal bar in parapet ar curb
d	½″φ	2	48′–00″	Top longitudinal bar in parapet an curb
e	½″φ	20	3′–03″	Vertical bar in parapet and curb
f	½′ φ	16	3 –06	Vertical bar in parapet and curb
g	½″φ	16	3′–09″	Vertical bar in parapet and curb
h	½″φ	16	4′–00″	Vertical bar in parapet and curb
m	½″φ	29	48′–06″	Longitudinal top and bottom slab ba
n	¼″φ	48	15′–05″	Longitudinal bar under I beams

Table of Excavation and Embankment
Road Approaches

Sta. to sta.	Exc. cy.	Emb. Cy.	Required borrow,	Remarks
75+50–78+50	......	700	800	Obtain from channel exc. pref erably above elev. 384.0
Drives	......	300 ±	400	Obtain from channel exc. pref erably above elev. 384.0
78+95–81+50	100	1,000	1,200	Obtain from channel exc. pref erably above elev. 384.0
Creek Channel and Structural Excavation Backfill				
2+40–S–1+00–N	4,300 ±	600 ±	....	Use best materials for road fill and abutment backfills

Typical Plans (7). Tabular information for contractors and inspectors.

Utilization of Old Structures. *Case* 1.—Where abutments and perstructure are properly located and of standard strength, but e roadway is too narrow, the structure is widened (see Fig. *A*, low).



'IG. *A*.—Utilization of old structures, Case 1. Old superstructure and abutments retained and extended.

Vote.—In this particular case the widening cost $3000 less than a new structure.

Case 2.—Where the abutments are good but the superstructur[e is] too weak for modern loads the method used in Fig. *B* is ofte[n] desirable and is a money saver.

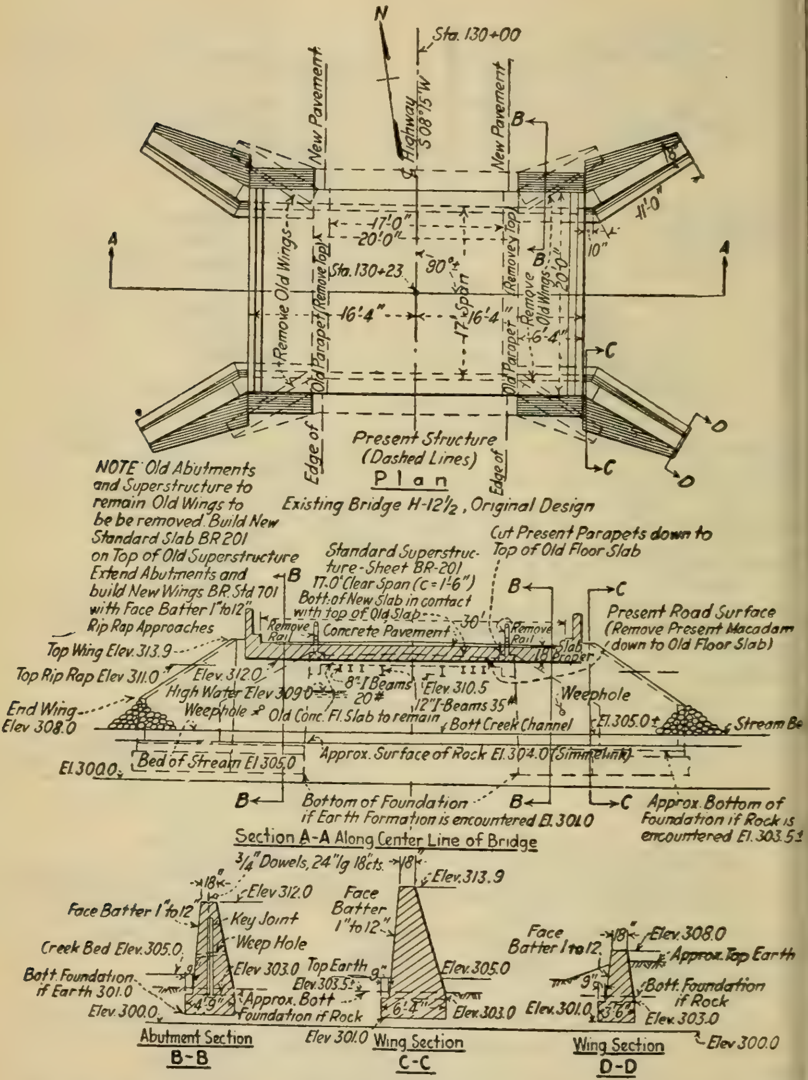


FIG. *B*.—Utilization of old structures, Case 2. Saved $1500 over entire new structure.

Case 3.—Where the abutments are good but where superstructure is either of a type which cannot be widened or is unsuitable to act as a form for a new deck, the existing superstructure is abandoned and the abutments utilized as shown in Figs. *C* and *D* (pp. 1015 and 1017).

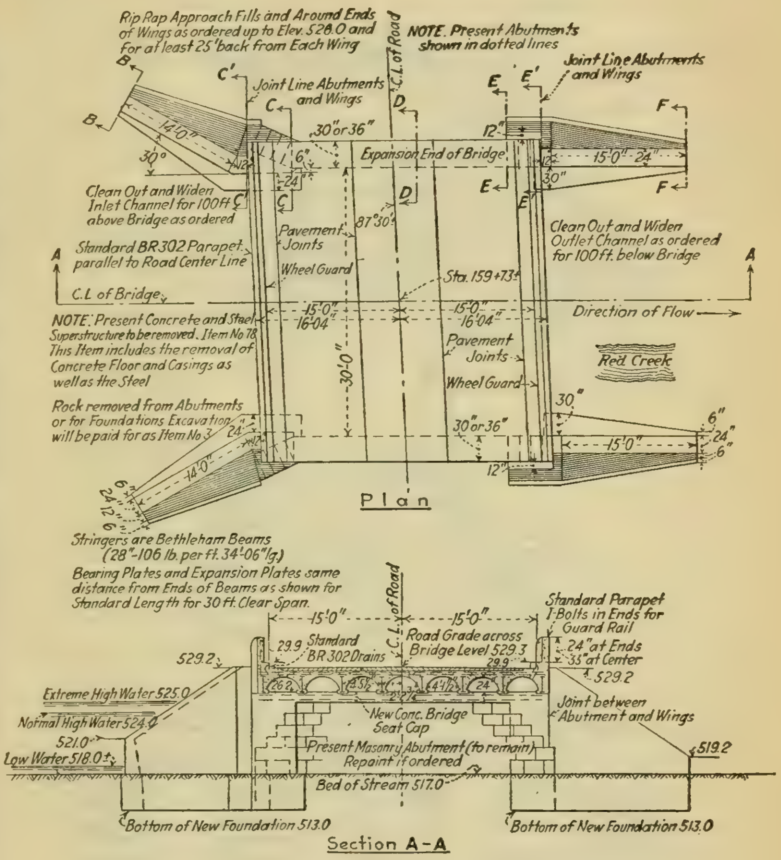


FIG. *C*.—Utilization of old structures, Case 3.

Note.—In this case utilization of old masonry resulted in a reduction in cost of approx. $2500.

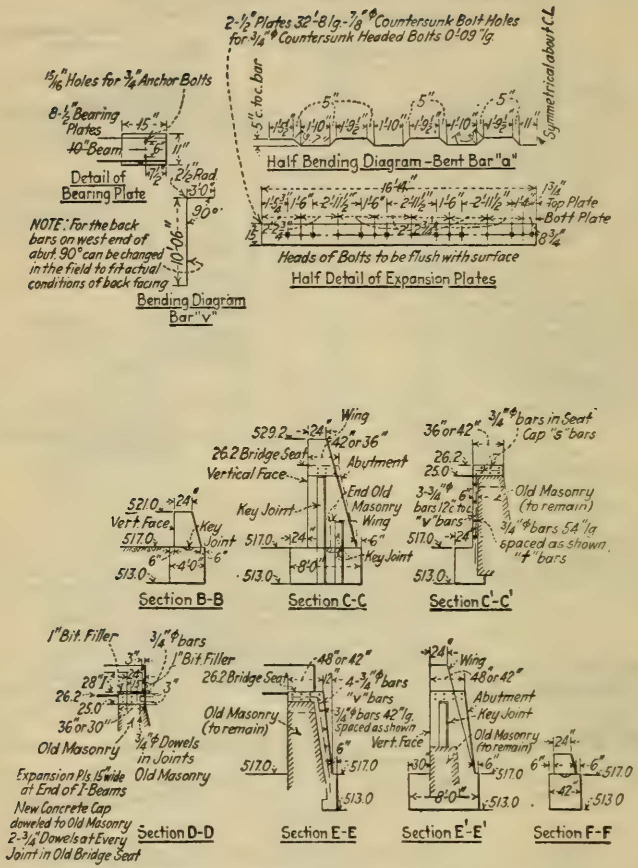


FIG. C.—(*Continued.*)

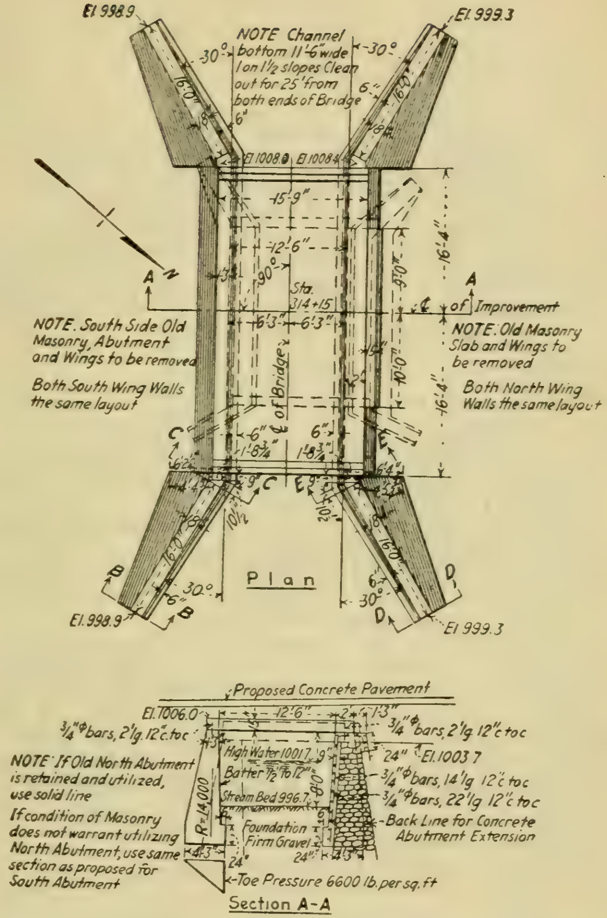


FIG. *D*.—Utilization of old structures, Case 3. Face and extend one abutment.

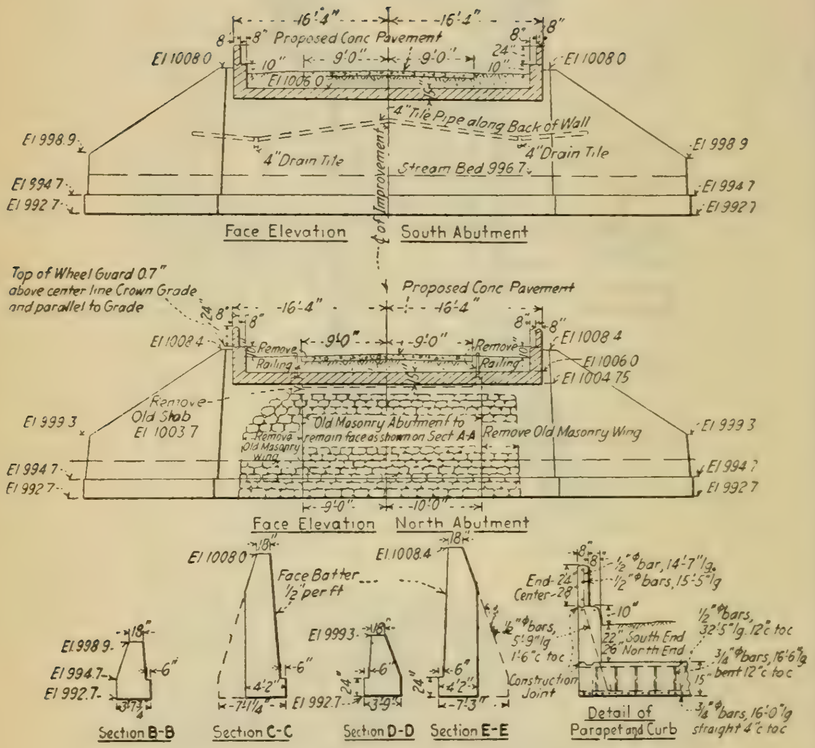


FIG. *D*.—(*Continued.*)

Case 4.—Where the arch type of bridge is suitable the abutment esign can be radically cheapened as shown in Fig. *E* if the old butments are solid and firm.

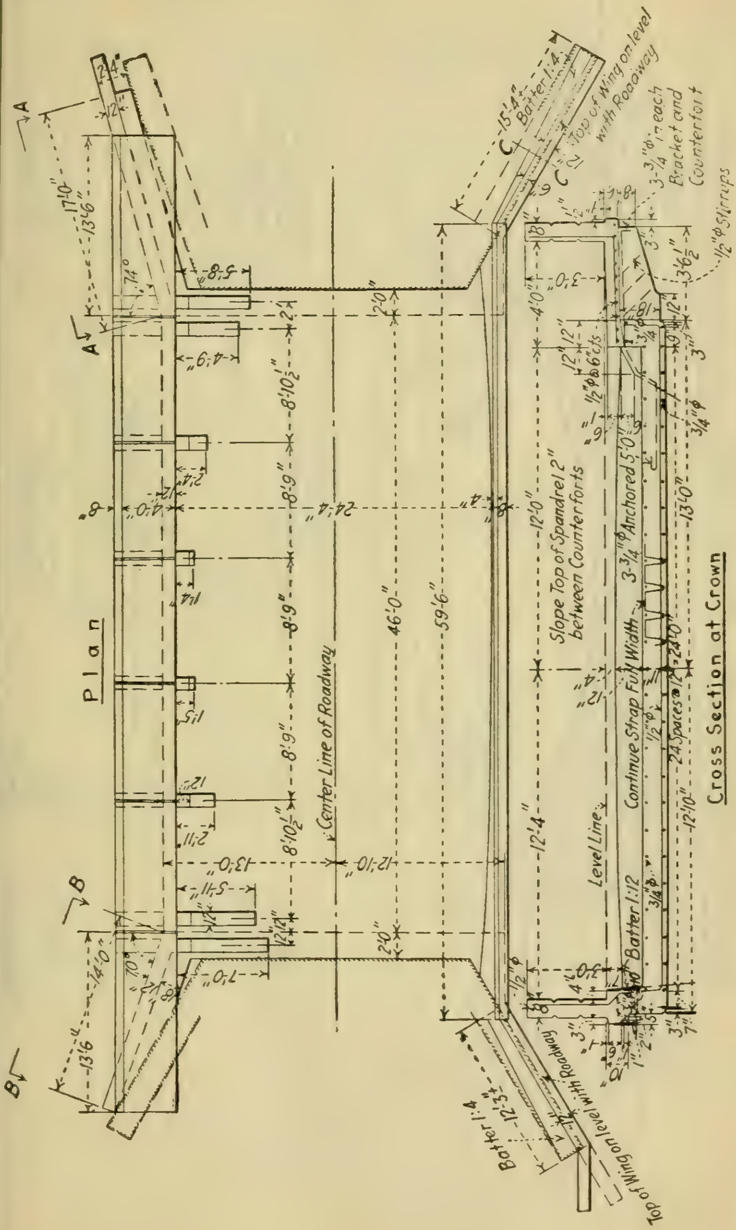
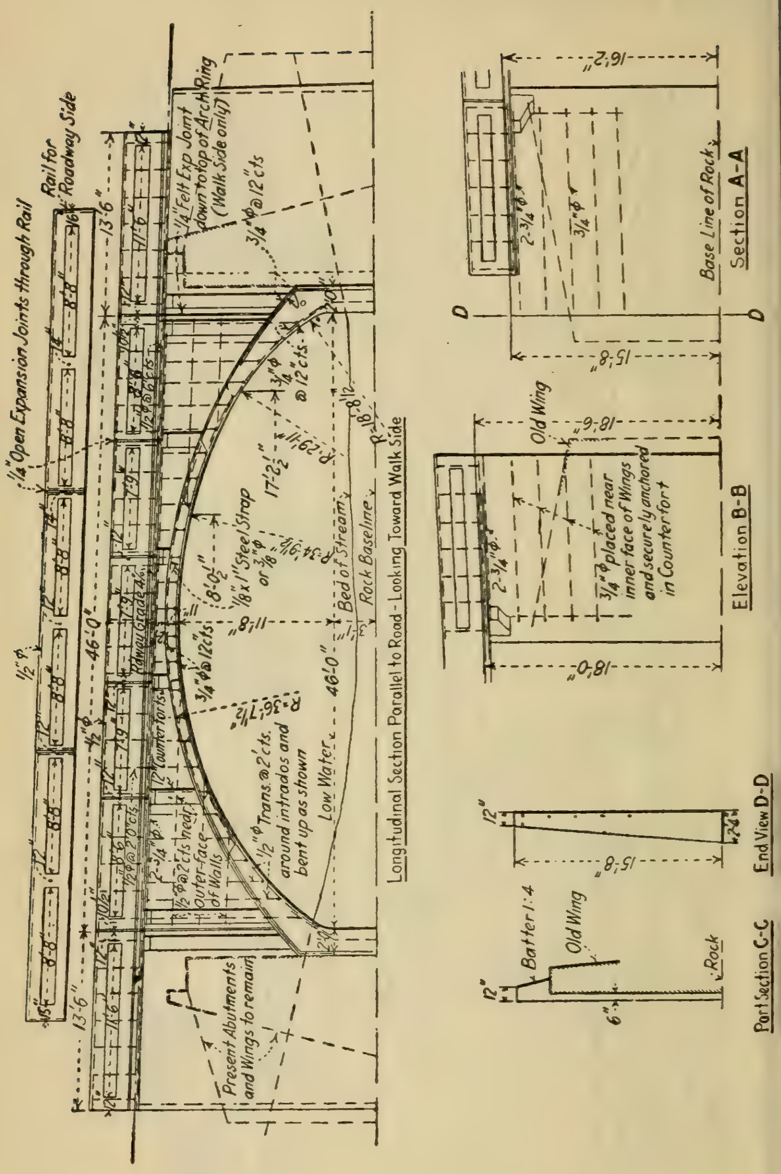
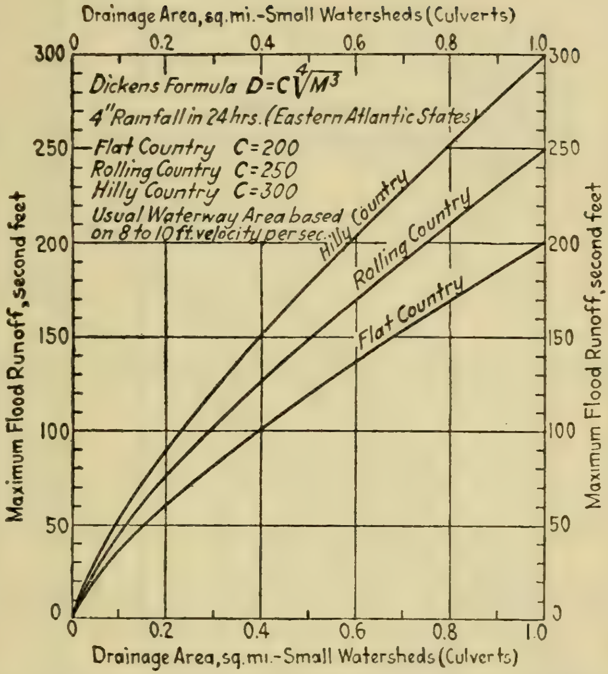


FIG. *E*.—Utilization of old structures, Case 4.


1/4" Open Expansion Joints through Rail
Rail for Roadway Side
1/4" Felt Exp Joint down to top of Arch Ring (Walk Side only)
Present Abutments and Wings to remain
Roadway Grade
12" Counterforts
1/2"Φ @2'cts near outer face of Walls
1/2"Φ Trans. @2'cts. around intrados and bent up as shown
1/8"x1" Steel Strap or 3/8"Φ
Low Water
Bed of Stream
Rock Baseline
46'-0"
13'-6"
Longitudinal Section Parallel to Road - Looking Toward Walk Side
Base Line of Rock
Section A-A
16'-2"
15'-8"
Old Wing
3/4"Φ placed near inner face of Wings and securely anchored in Counterfort
18'-6"
18'-0"
Elevation B-B
End View D-D
Batter 1:4
Old Wing
Rock
Part Section C-C



IAGRAM 1.—Flood runoff for small streams. N. Eastern States.
(See Table 47, page 189.)

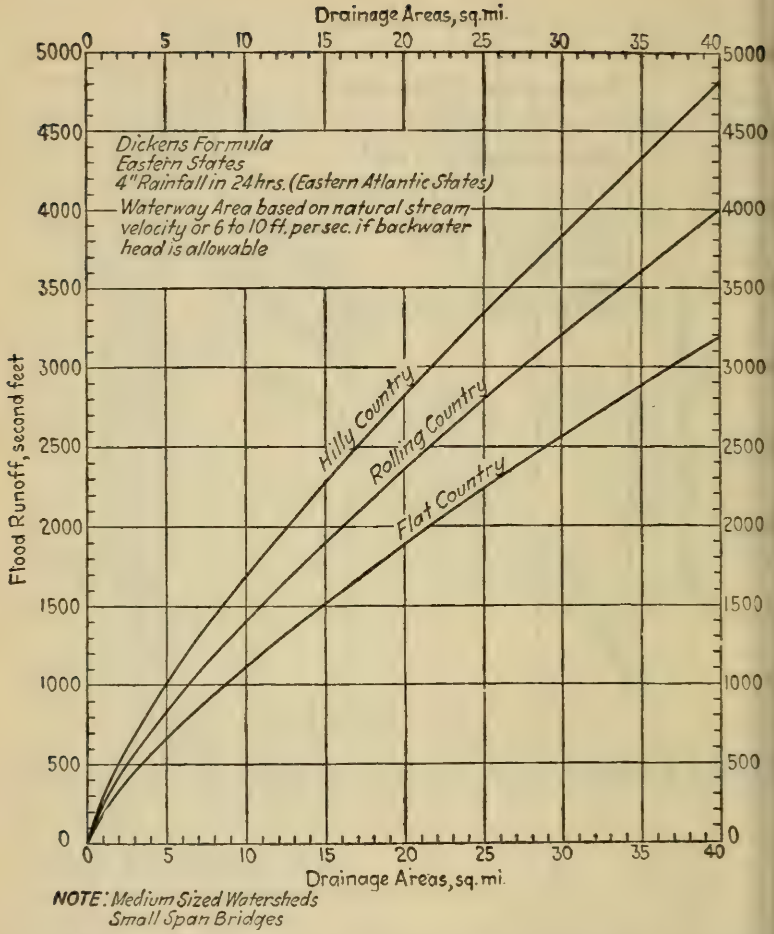


DIAGRAM 2.—Flood runoff for streams. Medium size watershed N. Eastern States.

(see table 47 on page 189.)

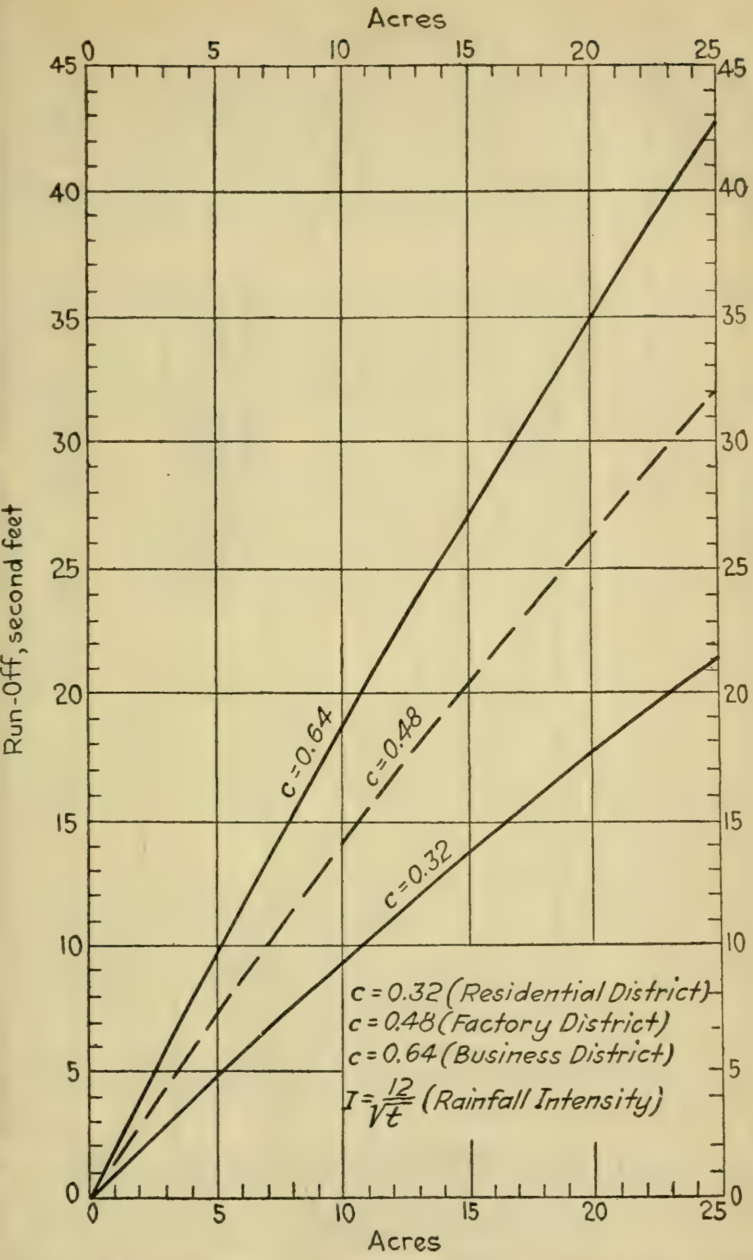


DIAGRAM 3.—Typical storm sewer runoffs. Lima, Ohio. (Rather flat topography.)

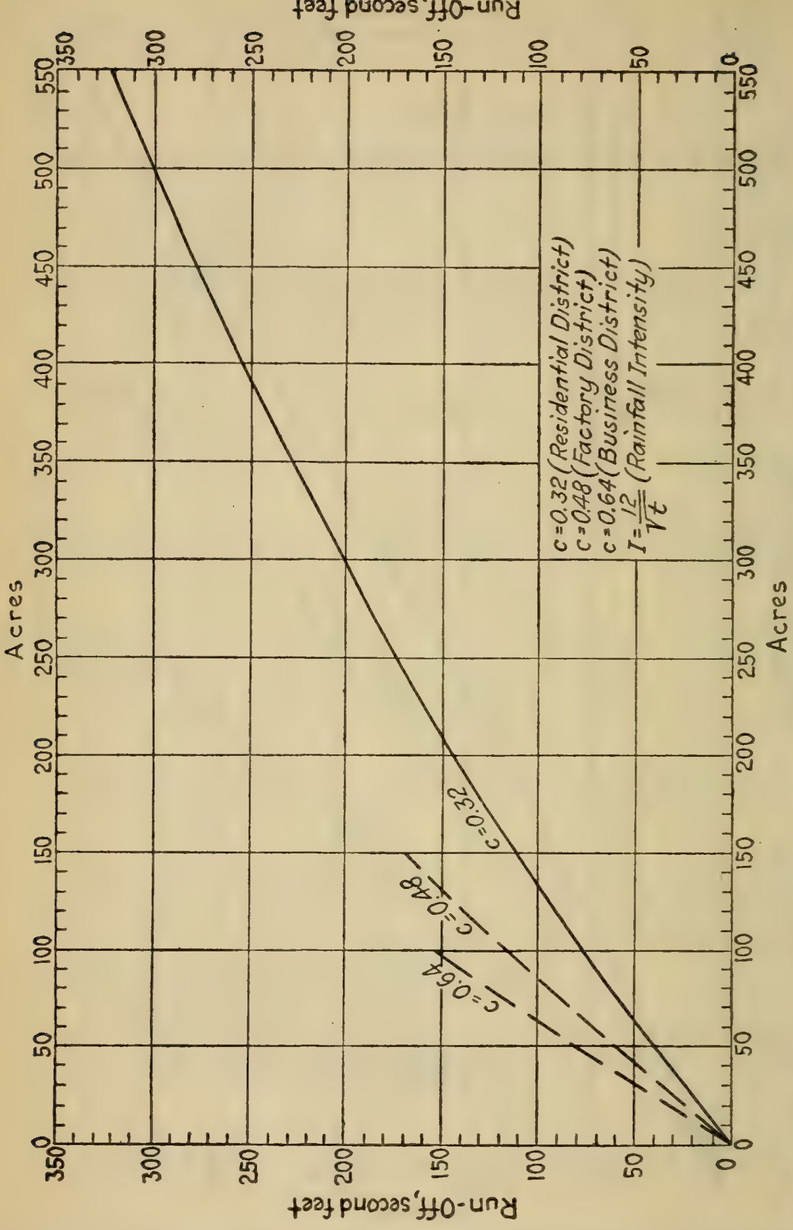


DIAGRAM 4.—Typical storm sewer runoffs. Lima, Ohio. (Rather flat topography.)

Elevation of Road Grade across Bridge.—The elevation of road grade across structure depends on elevation of high water, debris clearance and floor depth. The following data which was compiled for New York Standards (1926) gives a good general idea of the clearance data required for this part of the design. Similar data can be compiled for each locality using the prevailing clearances for that district. For special cases standard floor depths can be reduced 6″ to 9″ for approx. $200 to $400.

CLEARANCES ABOVE HIGHWATER[1] TO DETERMINE APPROXIMATE ROAD GRADE OVER BRIDGES

New York State Standards (1926) H-20 loading

Span (ft.)	Minimum debris clearance (ft.)	Depth floor slab bridges	Depth floor I-beam bridges	Depth floor T-beam bridges
6	0.5	1.2′		
10	0.5	1.4′	2.0′	
15	0.8	1.7′	2.5′	
20	0.8	2.0′	2.7′	
25	0.9	2.4′	3.0′	2.6′
30	1.0	...	3.0′	3.0′
35	1.2	...	3.4′	3.7′
40	1.5	...	3.4′	4.5′
45	2.0	...	3.4′	

	Depth road surface to bottom steel	Debris and ice clearance
22′ roadway plate girders (50 to 90′ spans)...	3.0′-3.5′	2.0′ to 4.0′
30′ roadway plate girders (50 to 90′ spans)...	3.5′-4.0′	2.0′ to 4.0′
40′ roadway plate girders....................	4.0′-4.5′	2.0′ to 4.0′
22′ roadway truss bridges (90′ or more spans..	3.5′	2.5′ to 4.0′
30′ roadway truss bridges (90′ or more spans).	4.3′	2.5′ to 4.0′

[1] NOTE: Highwater elevation is the upstream backwater head elevation to produce desired velocity through opening for sluggish streams or normal upstream highwater where natural stream velocity is maintained. Approx. backwater head in feet $= \frac{V^2}{64}$ where V equals desired increase in natural flow velocity in feet per second. (For table see page 196.)

Example.—Assume that new bridge is to be built across outlet stream emptying into a lake with dead water at bridge site. Assume 6′ per second is desired at bridge opening and that lake highwater is 248.3. Assume that an 80′ plate girder bridge with 22′ roadway is to be built. Assume debris clearance of 2.5′.

Backwater head $= \frac{6^2}{64} = \frac{36}{64} = 0.57' =$ say $0.6'$

Backwater head elevation $248.3 + 0.6 = 248.9$

Required elevation of bottom of steel =

$248.9 + 2.5$ debris clearance $= 251.4$

Road grade $= 251.4 + 3.0$ floor depth $= 254.4$

Design of Forms.—Design of strength of concrete forms for abutments and wings depends entirely on the speed with which the concrete is deposited. If these structures are constructed in short sections and poured monolithic from bottom to top in a short time (less than 2 hr.) they should be designed for horizontal pressures resulting from the depth of concrete laid in that time. If a small mixer is used and the level of the concrete is raised in successive shallow layers, each one of which has time to set before the next layer is placed, less studding, whales and ties are required. Figures 348 to 354 (pp. 1346 to 1353) show common practice for structures of different types.

Deck and girder forms are generally designed for total weight of concrete plus 50 lb. per square foot live load and assume that the concrete is carefully deposited and not dropped in large masses.

Table 181 (p. 1052) gives usual design values for horizontal fluid pressure of concrete against forms.

List of Structural Design and Estimating Data

For trial dimensions for preliminary computations of retaining walls see page 682; for abutments and bridge details see Chap. IV, Part I.

Structural Plans.—Structural plans should be completely detailed and very thoroughly dimensioned so that the contractor and inspector will have no difficulty in constructing to the correct lines and grades. All foundation plans should show the base-pressure diagram, so that reasonable decisions in regard to foundation modifications in widths of footage and pile layouts can be made by the constructing engineer when unexpected foundation conditions develop (see Fig. 321 illustrating base-pressure diagram.

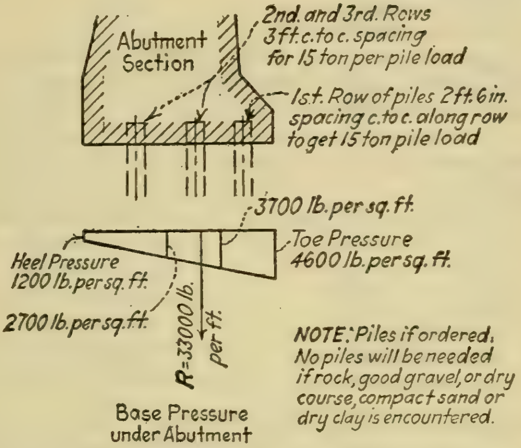
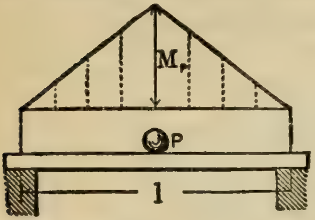


FIG. 321.—Typical base pressure diagram.

NOTE.—Piles if ordered. No piles will be needed if rock, good gravel, or dry, coarse, compact sand or dry clay is encountered.

Table 168.—Uniform Beams. Maximum Bending Moment and Deflections (Simple Cases)

Case 1. Beam with ends free. Single concentrated load P in middle of span; weight of beam disregarded.



Concentrated Load in Center of span

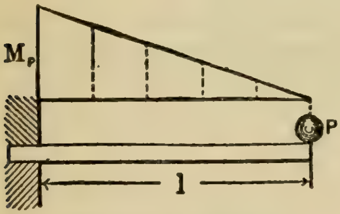
The maximum moment occurs at the center of the span.

$$M_p = \frac{Pl}{4}$$

The maximum deflection occurs at the center of the span.

$$D = \frac{Pl^3}{48\,EI}$$

Where D = the deflection in inches
P = load in pounds
l = span in inches
E = modulus of elasticity in lbs. per sq. inch
I = moment of inertia in inches^4
M_p = maximum moment in inch pounds.



Cantilever Beam

Case 2. Cantilever beam concentrated load P; weight of beam disregarded.

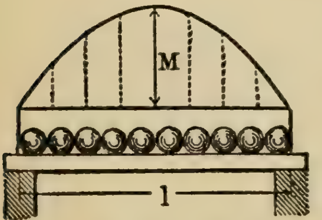
The maximum moment occurs at the support.

$$M_p = Pl$$

$$D = \frac{Pl^3}{3\,EI}$$

Case 3. Beam with ends free. Uniformly distributed load. The maximum moment occurs at the center of the span.

$$M = \frac{Wl}{8}$$



Uniform Load

The maximum deflection occurs at the center of the span.

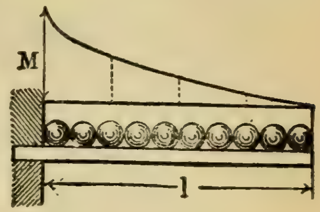
$$D = \frac{5}{384}\,\frac{Wl^3}{EI}$$

In these formulæ W equals the total uniformly distributed load.

Case 4. Cantilever beam. Uniform load W.

Maximum moment occurs at the point of support.

$$M = \frac{Wl}{2}$$

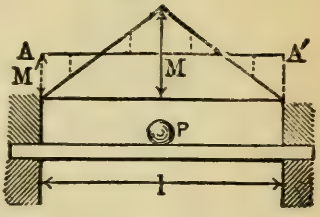


The maximum deflection occurs at the free end.

$$D = \frac{Wl^3}{8\,EI}$$

Case 5. Beam with fixed ends, concentrated load P in center of span; weight of beam disregarded.

The maximum bending moment occurs at the points of support and at the middle of the beam.



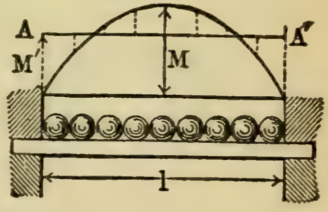
$$M = \frac{Pl}{8}$$

$$D = \frac{Pl^3}{192\,EI}$$

Case 6. Beam with fixed ends and a uniformly distributed load. Maximum bending moment occurs at the supports.

$$M' = \frac{Wl}{12}$$

$$M = \frac{Wl}{24}$$



Maximum deflection

$$= \frac{Wl^3}{384\,EI}$$

Resisting Moment of a beam is expressed by the formula

$$M_r = \frac{pI}{e}$$

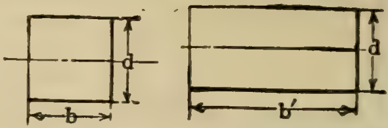
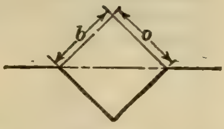
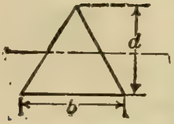
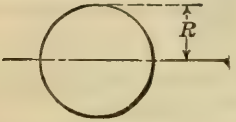
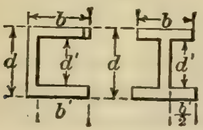
Where M_r = moment of resistance in inch pounds

p = maximum allowable fiber stress in lbs. per sq. inch.

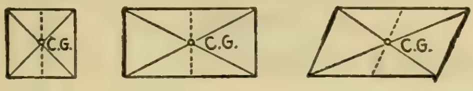
I = moment of inertia of the beam in inches[4]

e = distance in inches from the neutral axis to the outer fiber

TABLE 169.—MOMENTS OF INERTIA OF SIMPLE SECTIONS

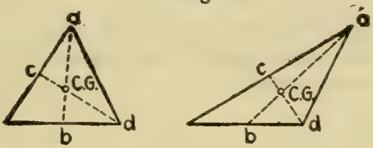
I = Moment of Inertia $I = \dfrac{bd^3}{12}$	
 Square	$I = \dfrac{b^4}{12}$
 Triangles	$I = \dfrac{bd^3}{36}$
 Circles	$I = 0.7854\,R^4$
	$I = \dfrac{bd^3 - b'd'^3}{12}$

BLE 170.—CENTERS OF GRAVITY OF ORDINARY PLANE FIGURES



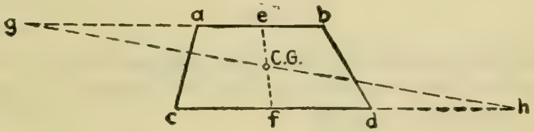
Squares, rectangles, parallelograms. Center of gravity is at : intersection of the diagonals or midway between the bases a line drawn between the centers of those bases.

Triangles



Center of gravity is at the intersection of the medial lines and *c d;* a medial line is a line drawn from any apex to the ddle of the opposite side The distance *b* (*C. G.*) = $\frac{1}{3}$ *a b;* that the center of gravity is on the medial line $\frac{1}{3}$ of the distance from e base to the apex.

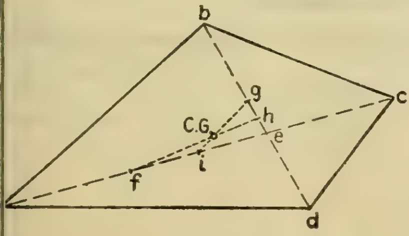
Trapezoid



Graphic Method. Prolong *b a* to *g*, making *a g* = *c d*. Pro-ng *c d* to *h*, making *d h* = *a b*. Connect *g h*. Bisect *a b* at *e*. sect *c d* at *f*. Connect *e f:* the intersection of *g h* and *e f* is e center of gravity.

The distance $f\ (C.G.) = \frac{ef}{3} \times \frac{2\,ab + cd}{ab + cd}$

Any Quadrilateral



Graphic Method. Draw the diagonals *a c* and *b d* intersecting at *e*.

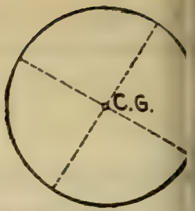
Lay off *a f* = *e c*
Lay off *b g* = *e d*

Bisect *e g* at *h*; bisect *e f* at *i*.

The intersection of *f h* and *g i* is the center of gravity of the figure.

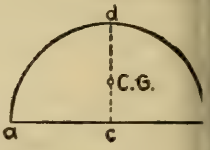
Circles

Center of gravity at the center



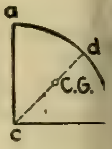
Semicircle

The center of gravity lies on the radius perpendicular to the diameter. The distance c ($C.G.$) = radius × 0.4244



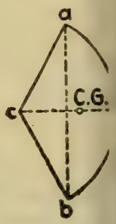
Quadrant

The center of gravity lies on the radius which bisects the ∠ acb. The distance c ($C.G.$) = radius × 0.6002



Sector

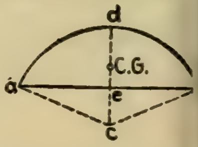
The center of gravity lies on the radius bisecting the ∠ acb. The distance c ($C.G.$) = $\frac{2}{3}$ radius × $\frac{\text{chord } ab}{\text{arc } adb} = \frac{\text{radius}^2 \times \text{chord}}{3 \times \text{area}}$



Segment

The center of gravity lies on the perpendicular erected at the center of the chord ab.

The distance c ($C.G.$) = $\frac{\overline{\text{chord } ab}^3}{12 \times \text{area of segment}}$



ABLE 171A.—GIVING MODULI OF ELASTICITY, WORKING STRESS AND ULTIMATE STRENGTH

MODULI OF ELASTICITY	
Material	Lbs. per Sq. In.
Concrete	2,000,000
Hemlock	900,000
Iron (cast)	17,500,000
Iron (wrought)	29,000,000
Oak	1,500,000
Pine (white)	1,600,000
Pine (yellow)	1,600,000
Steel (medium)	30,000,000
Spruce	1,600,000

WORKING STRESSES IN LBS. PER SQUARE INCH

Material	Tension	Compression	Shear
Concrete	60	600	60 to 100
Hemlock	600	W. G.[1] 600 A. G.[2] 150	W. G. 100 A. G. 600
Iron (cast)	3,000	18,000	5,000
" (wrought)	10,000	8,000	8,000
Oak	1,200	W. G. 1,200 A. G. 500	W. G. 200 A. G. 1,000
Pine (white)	700	W. G. 700 A. G. 200	W. G. 100 A. G. 500
" (yellow)	1,200	W. G. 1,200 A. G. 350	W. G. 150 A. G. 1,250
Steel (medium)	12,000	12,000	12,000
Spuce	800	W G. 800 A. G. 200	W. G. 100 A. G. 750

ULTIMATE STRENGTH IN LBS. PER SQUARE INCH

Material	Tension	Compression	Shear
Concrete	300	3,000	1300
Hemlock	6,000	W. G. 6,000 A. G. 600	W. G. 350 A. G. 2,500
Iron (cast)	18,000	90.000	20,000 to 30,000
" (wrought)	50,000	40,000	35,000 to 55,000
Oak	12,000	W. G 7,000 A. G. 2,000	W. G. 800 A. G. 4,000
Pine (white)	7,000	W G. 5,500 A. G. 700	W. G 400 A. G. 2,000
" (yellow)	12,000	W. G. 7,000 A. G. 1,400	W. G. 600 A. G. 5,000
Steel (medium)	60,000	60,000	50,000 to 70,000
Spruce	8,000	W. G. 6,000 A. G. 700	W. G. 400 A. G. 3,200

[1] W. G. — With Grain. [2] A. G. — Across Grain.

TABLE 171*B*

UNIT STRESSES

Pounds per square inch

Steel Structures

Structural grade and rivet steel:	
Tension:	
Axial tension, structural members, net section	16,000
Rivets in tension, where permitted—50 % of single shear values	
Bolts, area at root of thread	10,000
Axial compression:	
Axial compression, gross section	15,000–50 L/
But not to exceed	13,500
L = length of member, in inches	
r = least radius of gyration; in inches	
Bending on extreme fiber:	
Rolled shapes, built sections and girders, net section	16,000
Pins	24,000
Shear:	
Girder webs, gross section	10,000
Pins and shop-driven rivets	12,000
Power-driven field rivets and turned bolts	10,000
Hand-driven rivets and unfinished bolts	7,500
Bearing:	
Pins, steel parts in contract and shop-driven rivets	24,000
Power-driven field rivets and turned bolts	20,000
Hand-driven rivets and unfinished bolts	15,000
Expansion rollers, pounds per linear inch, where d = diameter or roller in inches	600d
Countersunk rivets:	
In metal ⅜″ thick and over, half the depth of countersink shall be omitted in calculating bearing area	
In metal less than ⅜″ thick, countersunk rivets shall not be assumed to carry stress	
Diagonal Tension	
In webs of girders and rolled beams, at sections where maximum shear and bending occur simultaneously	16,000
Other metals:	
Apial Tension:	
Wrought iron	12,000
Bending on extreme fiber:	
Cast steel	12,000
Cast iron	3,000
Shear:	
Cast steel	10,000
Cast iron	3,000
Bearing:	
Cast steel	14,000
Cast iron	10,000
Bronze sliding expansion bearings	3,000
Bearing on bridge seats:	
Bearing on concrete masonry limestone masonry and better	500

Concrete Structures

Concrete:	
Direct compression:	
Columns reinforced with longitudinal bars and separate lateral ties	600–15 L/D
But not to exceed	450
L = unsupported length of column	
D = least diameter of column	
Piers and pedestals	450
Compression due to bending:	
Beams and slabs	650
Archs rings, including temperature and rib shortening	800
Tension	[illegible]

TABLE 171*B*—*Continued.*

Shear (diagonal tension):	
Beams without shear reinforcement:	
Longitudinal bars not anchored	40
Longitudinal bars anchored	60
Beams with shear reinforcement	120
Punching shear	120
Reinforcement:	
Tension:	
Beams and slabs	16,000
Arch rings, including temperature and rib shortening	20,000
Compression—15 times stress in surrounding concrete.	
Bond:	
Bars not anchored	80
Bars adequately anchored by hooks or otherwise	120

TABLE 171*C*.—ALLOWABLE WORKING STRESSES

(*Ketchum's "Design of Highway Bridges"*) 1:2:4 concrete (2000-lb. compression, 28-day age)

"The following working stresses are for static loads and are based on a concrete composed of 1 part Portland Cement, 2 parts sand or fine aggregate, and 4 parts stone or coarse aggregate, that will develop an ultimate compressive strength of 2000 lb. per square inch at an age of 28 days in cylinders 8″ in diameter and 16″ long, when made and stored in moist air under laboratory conditions. Concretes of diffierent mixtures shall have allowable stresses proportional to their ultimate compressive strengths determined under the above conditions.

"**Bearing.**—When compression is applied to a surface of concrete having at least twice the loaded area, a stress of 700 lb. per square inch may be allowed on the area actually under load.

"**Axial Compression.**—For concentric compression on a plain concrete pier, the length of which does not exceed four diameters, a stress of 450 lb. per square inch may be allowed.

"**Columns.**—Reinforced-concrete columns may have allowable stresses as follows:

"*a.* Columns with longitudinal reinforcement of not less than 1 and not more than 4 %, and with lateral ties of not less than ¼″ in diameter, 12″ apart, nor more than 15 diameters of longitudinal bar may have an allowable stress in the concrete of 450 lb. per square inch.

"*b.* Columns with longitudinal reinforcement of not less than 1 and not more than 4 %, and with circular hoops or spirals not less than 1 % of the volume of the concrete, where the hoops are spaced not more than one-sixth the diameter of the enclosed column or more than 2½″, may have an allowable stress in the concrete of 700 lb. per square inch.

"**Compression on Extreme Fiber.**—The extreme fiber stress of a beam, calculated on the assumption of a constant modulus of elasticity of concrete, shall not exceed 650 lb. per square inch. Adjacent to the support of continuous beams, stresses 15 % higher may be used.

"**Shear and Diagonal Tension.**—As a measure of diagonal tension the following allowable shearing stresses may be used.

"*a.* For beams with horizontal bars only and without web reinforcement, a shearing stress of 40 lb. per square inch may be allowed.

"*b.* For beams with web reinforcement of stirrups looped about longitudinal reinforcing bars in the tension side of the beam and spaced horizontally, not more than one-half the depth of the beam or for beams in which longitudinal bars are bent up at an angle of not more than 45 nor less than 20° with the axis of the beam, and the points of bending are spaced horizontally not more than three-quarters the depth of the beam, a shearing stress of 90 lb. per square inch may be allowed.

"*c.* For a combination of bent bars and vertical stirrups looped about reinforcing bars on the tension side of the beam and spaced horizontally not more than one-half the depth of the beam, a shearing stress of 100 lb. per square inch may be allowed.

"*d.* For beams with web reinforcement (either vertical or inclined) securely attached to the longitudinal bars on the tension side of the beam in such a way as to prevent slipping of bar past the stirrups, vertical stirrups

FIG. 171*C*—*Continued*

to be spaced not more than one-half and inclined members not more thai three-fourths the depth of the beam, either with longitudinal bars bent u] or not, a shearing stress of 120 lb. per square inch may be allowed.

"*e.* For punching or pure shear, 120 lb. per square inch may be allowed.

"In calculating the stresses in web reinforcement two-thirds of the externa vertical shear is to be assumed as taken by the stirrups or bent-up bars The stresses in stirrups when combined with bent-up bars are to be deter mined by finding the total amount of shear that may be allowed by reasoi of the bent-up bars, and subtracting this shear from the total external vertica shear. Two-thirds of the remainder will be the shear to be carried by th stirrups.

"**Bond Stress.**—The bond stress between concrete and plain reinforcin bars may be assumed at 80 lb. per square inch; on drawn wire 40 lb. per squar inch; on deformed bars 100 lb. per square inch. Bars with ends hooked b bending through 180° around a radius of two diameters of bar may have bond stress of 120 lb. per square inch.

"**Stresses in Steel Reinforcement.**—The tensile or compressive stress i steel reinforcement shall not exceed 16,000 lb. per square inch. The tensil stress in stirrups shall not exceed 12,000 lb. per square inch."

TABLE OF VALUES OF MODULUS OF RUPTURE OF REINFORCEI CONCRETE

Per cent of reinforcement	Modulus of rupture, pounds per square inch	Design value for factor of safety of 4, pounds per square inch
0 to 0.2	400 to 600	100
0.4	1,000	250
0.5	1,250	310
0.6	1,350	340
0.7	1,500	380
0.8	1,600	400
0.9	1,675	420
1.0	1,750	440

1:2:4 mix concrete.

TABLE 171*D*.— AVERAGE SAFE ALLOWABLE WORKING UNIT STRESSES OF TIMBER IN POUNDS PER SQUARE INCH

Kind of timber	Tension		Compression			Transverse		Shearing	
	With grain	Across grain	With grain: End bearing	With grain: Columns under 15″ diameters	Across grain	Extreme fiber stress	Modulus of elasticity	With grain	Across grain
Factor of safety...........	10	10	5	5	4	6	2	4	4
White oak................	1,200	200	1,400	1,000	500	1,200	750,000	200	1,000
White pine...............	700	50	1,100	700	200	700	500,000	100	500
Southern longleaf or Georgia pine...............	1,200	60	1,400	1,000	350	1,200	750,000	150	1,250
Douglas fir...............	800	...	1,100	900	200	800	750,000	130	.....
Short-leaf yellow pine......	900	50	1,200	900	250	1,000	600,000	100	1,000
Red pine (Norway pine)....	800	50	1,000	800	200	800	565,000	...	.....
Spruce and eastern fir......	800	50	1,200	800	200	700	600,000	100	750
Hemlock.................	600	...	.....	800	150	600	450,000	100	600
Cypress..................	600	...	1,000	800	200	800	450,000	...	.....
Cedar...................	700	...	1,100	700	200	700	350,000	100	400
Chestnut.................	850	...	.....	800	250	800	500,000	150	500
California redwood	700	...	.....	800	150	750	350,000	100	.....
California spruce..........	.....	...	.....	800	...	800	600,000	...	.....

The above tables are based on those recommended by the committe on Strength of Bridge and Trestle Timbers of the Association of Railway Superintendents of Bridges Buildings at their Fifth Annual Convention in October, 1895, but the arrangement and values in many cases are now modified by later data from various sources.

TABLE 172.—DEAD LOAD WEIGHTS OF DIFFERENT MATERIAL PER CUBIC FOOT[1]

Material	Weight per Cu. Ft.	
Ash timber	40	lbs.
Brick (pressed)	150	"
" (common building)	125	"
Cement (Portland)	75 to 90	"
" (Natural	50 to 56	"
Concrete 1:2:4 Mixture (Trap rock)	155	"
" (Gravel)	152	"
" (Limestone)	150	"
" (Sandstone)	145	"
" (Cinder)	110	"
" 1:3:6 Mixture (about 5 lbs. less)	—	"
Earth (common loam, loose and dry)	70	"
" (common loam, moist and rammed)	100	"
" (sand or gravel loose and dry)	100	"
" (sand or gravel rammed)	120	"
" (sand or gravel wet)	120	"
Hemlock timber	25	"
Hickory "	50	"
Iron (cast)	450	"
" (wrought)	480	"
Maple timber	50	"
Oak " (white)	48	"
" " (black)	40	"
Masonry (dressed granite or limestone)	165	"
" (mortar rubble)	155	"
" (dry ")	125	"
Pine (white)	25	"
" (northern yellow)	34	"
" (southern yellow)	40	"
Steel	490	"
Water	62.5	"

[1] For weight of road rocks, see Tables 120 and 121 (p. 709).

Miscellaneous Weights

1 bbl. Portland cement ....376 lbs.
1 bbl. natural cement ....235 lbs.
1 gal. water ....8.345 lbs.

TABLE 173.—LIVE LOADS, HIGHWAY BRIDGES

Floor Loads:

H-20 = 20-ton gross truck load.
H-15 = 15-ton gross truck load.
H-12½ = 12½-ton gross truck load.
H-10 = 10-ton gross truck load.
14′ front to rear axle.
6′ gage between rear wheels.
0.8 of gross load on rear axle.
0.2 of gross load on front axle.
Width of rear tires, 1″ per ton of gross load.
Total area occupied by single truck 9′ wide 25′ long (see also Fig. 64*B*, Chap. IV, for electric cars and freight cars).

Girder and Truss Loads:[1]

H-20 = total load on each traffic lane 9′ wide, of 600 lb., per linear foot plus 28,000 lb. concentrated.
H-15 = 450 lb. per linear foot plus 21,000 lb. concentrated.
H-12½ = 375 lb. per linear foot plus 17,500 lb. concentrated.
H-10 = 300 lb. per linear foot plus 14,000 lb. concentrated.

Sidewalk Loads:
Class A bridges,

$$P = \left(25 + \frac{2250}{L}\right)\left(\frac{W + 5}{W}\right)$$

not to exceed a maximum of 100 lb. per square foot.

P = live load, in pounds per square foot.
L = loaded length, in feet.
W = width of sidewalk, in feet.

Class B and C bridges, use 80% of this loading.

[1] For proper use of these different classes of loading see Chap. IV (p. 202).

Table 174.—Impact Loads

Impact:

The extra design load allowance for impact of moving loads is subject to considerable difference in practice ranging from 0 to 60% of the static weight of the vehicles.

As a general rule, the following values represent conservative practice in impact allowance:

Floor systems of bridges having timber plank floor surface.. 30–50%

Floor systems of bridges and trestles having concrete floor slabs supported by stringers or floor beams.... 20–30%

For end floor beams, floor beam hangers, or connections..... 60% of live load.

For stringers, floor beams, girders, and trusses on concrete floor bridges the impact allowance shall not exceed 30% and, in general, may be determined by the formula

$$\text{Impact} = \frac{L + 250}{10L + 500}.$$

L = loaded length in feet producing the maximum static stress in the member considered.

N. Y. State 1926 Standard Bridges Approximate Equivalent Uniform Static Design Live Loads

(H-20 loading plus impact in pounds per square foot of bridge floor)

Span, feet	Type of bridge superstructure		
	Concrete slab bridges, pounds	Steel-beam stringers, pounds	Girders and trusses, pounds
6	1,200		
8	850		
10	650	650	
15	400	400	
20	250	300	
25	200	250	
30	.....	200	
40	.....	170	220
45	.....	150	210
50	.....	...	200
100	.....	...	160
150	.....	...	140
200	.....	...	120

TABLE OF UNIFORM LIVE LOADS FOR HIGHWAY BRIDGES[1]

Illinois Highway Commission		Iowa Highway Commission		Wisconsin Highway Commission		American Concrete Institute, 1916				Ketchum's Specifications, 1918			
						Class A		Class B		Class D_1		Class D_2	
Span, ft.	Load, lb./sq. ft.	Span, ft.	Load, lb./sq. ft.	Span, ft.	Load, lb./sq. ft.	Span, ft.	Load, lb./sq. ft.	Span, ft.	Load, lb./sq. ft.	Span, ft.	Load, lb./sq. ft.	Span, ft.	Load, lb./sq. ft.
Up to 50	125	Up to 50	100	Up to 40	125	Up to 80	125	Up to 80	100	30	125	30	100
50–100	100	50–100	90	50	120	80–100	110	80–100	90	50	106	50	90
100–150	100	100–150	80	75	106	100–125	100	100–125	80	80	85	80	75
150–200	85	150–200	70	100	93	125–150	90	125–150	75	100	80	100	71
Over 200	85	200–250	50	150	60	150–200	85	150–200	65	160	68	160	60
		Over 250	50	180 and over	50	Over 200	80	Over 200	60	200 and over	60	200 and over	50

Class D_1 and D_2 bridge loadings to be increased for impact.

[1] Compiled by Ketchum and reproduced from Ketchum Highway Bridges, McGraw-Hill Book Company, Inc., by permission.

Table 175.—Distribution of Live Loads on Slabs, Floor Beams, and Stringers (New York Specifications)

"**Through Earth Fills.**—When the depth of fill is 3′ 0″ or more, concentrated loads shall be considered as uniformly distributed over a square, the sides of which are equal to one and three-fourth times the depth of fill. When such areas from several concentrations overlap, the total load shall be considered as uniformly distributed over the area defined by the outside limits of the individual areas, but the total width of distribution shall not exceed the total width of the supporting slab. For single spans, the effect of live load may be neglected when the depth of fill is more than 4′ and exceeds the span length; for multiple spans it may be neglected when the depth of fill exceeds the distance between faces of end supports or abutments.

"**In Concrete Slabs.**—In calculating bending stresses due to wheel loads on concrete slabs no distribution in the direction of the span of the slab shall be assumed. In the direction perpendicular to the span of the slab the wheel load shall be considered as distributed uniformly over a width of slab which is known as the "effective width."

"In the following equations

Let S = span of slab, in feet.
W = width of wheel or tire, in feet.
X = distance, in feet, from the center of the near support to the center of wheel.
E = effective width, in feet, for one wheel.

"*Case I. Main Reinforcement Parallel to Direction of Traffic.*

$$E = 0.7\ S + W.$$

"For this case the value of E shall not exceed 5′.

"When two wheels are so located on a transverse element of the slab that their effective widths overlap, the effective width for each wheel shall be $\frac{1}{2}(E + a)$, where a is the distance between centers of wheels.

"*Case II. Main Reinforcement Perpendicular to Direction of Traffic.*

$$E = 0.7\ (2x + W)$$

"For this case the bending moment on a strip of slab 1′ in width shall be determined by placing the wheel loads in the position to produce maximum bending, determining the effective width for each wheel, and assuming the load delivered by each wheel to the 1′ strip to be the wheel load divided by its respective effective width.

"This investigation assumption does not provide for the effect of loads near unsupported edges.

In Longitudinal Beams or Stringers and in Transverse Floor Beams

"*Shear.*—In calculating end shears and end reactions in transverse floor beams and longitudinal beams or stringers, no lateral or longitudinal distribution of the wheel loads shall be assumed.

"*Bending Moment in Longitudinal Beams or Stringers.*—In determining bending moments in longitudinal beams or stringers no longitudinal distribution of the wheel loads shall be assumed. The lateral distribution may be determined in one of the following ways:

"*a. Absolute Method.*—For investigations in which extreme accuracy is desired the lateral distribution may be very closely determined by considering the flooring as continuous over a series of elastic supports and forming upon this hypothesis a series of work equations.

"*b. Approximate Method.*—For ordinary construction the lateral distribution may be determined by the following approximate method:

Let M = one-half the bending moment produced by one truck.
S = spacing of beams, in feet.
M_1 = bending moment in one interior beam when floor system is designed for one truck.
M_2 = bending moment in one interior beam when floor system is designed for two or more trucks.

$M_1 = \frac{MS}{4}$ for plank floors.

$M_1 = \frac{MS}{4.5}$ for strip floors 4″ in thickness and for wood blocks on a 4″ plank subfloor.

TABLE 175.—*Continued*

$M_1 = \frac{MS}{5.5}$ for strip floors 6″ or more in thickness.

$M_1 = \frac{MS}{6}$ for reinforced-concrete floors.

$M_2 = 1.2M_1$ for the type of floor involved.

"When the stringer spacing is such that M_1 or M_2, as the case may be, exceeds M, the stringer loads shall be determined by the reactions of the truck wheels, assuming the flooring between stringers to act as simple beams.

"*c. Outside Stringers.*—The live load supported by the outside stringer shall be the reaction of the truck wheels, assuming the flooring to act as a simple beam, but this live load shall in no case be less than would be required for interior stringers under the requirements specified above.

"*d. Total Capacity of Stringers.*—The combined load capacity of the beams in a panel shall not be less than the total live and dead load in the panel.

"*Bending Moment in Floor Beams.*—In determining bending moments in transverse floor beams, no transverse distribution of the wheel loads shall be assumed . . .

"When longitudinal stringers are omitted and the floor is supported directly on the floor beams, the longitudinal distribution shall be determined as follows:

Let M = total maximum bending moment due to the superimposed rear axle loads.
S = longitudinal spacing of floor beams, in feet.
M_1 = bending moment in one floor beam.

$M_1 = \frac{MS}{4}$ for plank floors.

$M_1 = \frac{MS}{4.5}$ for strip floors 4″ in thickness and for wood blocks on a 4″ plank subfloor.

$M_1 = \frac{MS}{5.5}$ for strip floors 6″ or more in thickness.

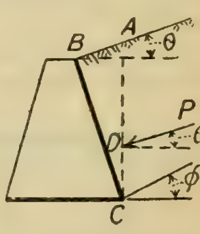
$M_1 = \frac{MS}{6}$ for reinforced-concrete floors.

"When the floor-beam spacing is such that M_1 as given by the above equations exceeds M the floor-beam loads shall be determined by the reactions of the truck wheels, assuming the flooring between floor beams to act as simple beams."

TABLE 176.—EARTH PRESSURE FORMULAE [1]

1*a*. Rankine's Formula for resultant Active Earth Pressure.—Rankine has developed the following formula[2] for the case in which (1) the total active thrust P acts upon a vertical plane, (2) acts parallel to the surface of the earth for all cases in which $\theta \geqq 0$, (3) acts in a material of indefinite extent, and (4) the earth carries no load except its own weight (Fig. 2):

$$P = C_e \frac{wh^2}{2}$$



in which

P = total active thrust of earth against the vertical plane as described above.
w = weight per cubic foot of retained material.
h = height of vertical section considered, as AC.

$$C_e = \cos\theta \cdot \frac{\cos\theta - \sqrt{\cos^2\theta - \cos^2\phi}}{\cos\theta + \sqrt{\cos^2\theta - \cos^2\phi}}.$$

[1] Hool and Johnson's Concrete Engineers Handbook, by permission of authors.

[2] For development see BAKER's "Masonry Construction," 10th Ed., p. 493.

TABLE 176.—*Continued*

where

θ = angle of surcharge.
ϕ = angle of internal friction.

Diagram I gives the values of C_e for various values of θ and ϕ. It should be noted that P is parallel to the surface AB, when θ is either positive, or zero; and that it acts at a point D, $\frac{h}{3}$ above C, or in other words, $CD = \left(\frac{AC}{3}\right)$.

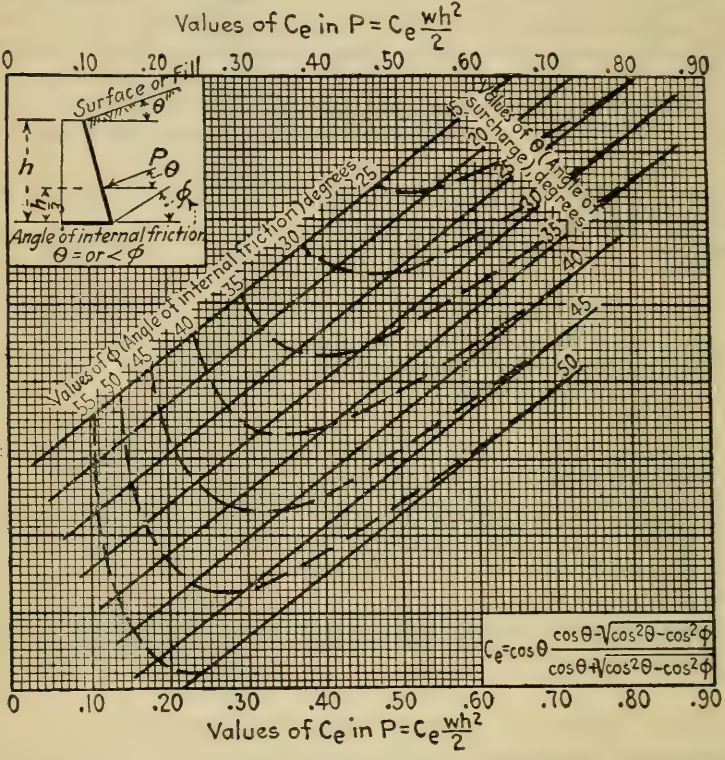


DIAGRAM I.

When $\theta = \phi$, then

$$P = \tfrac{1}{2}wh^2 \cdot \cos \phi$$

When $\theta = 0$

$$P = C_e' \frac{wh^2}{2}$$

in which

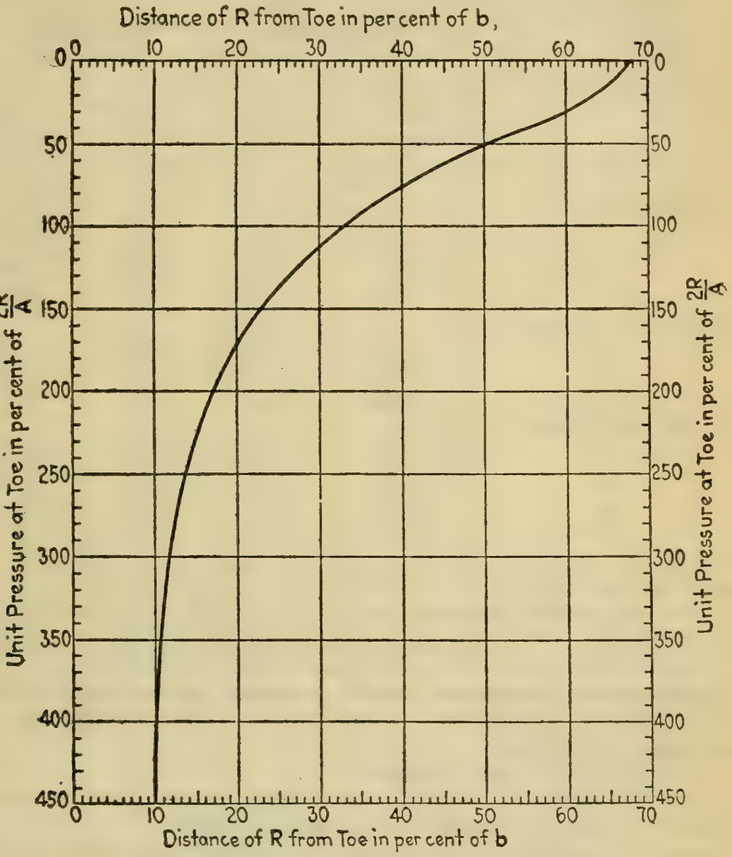
$$C_e' = \tan^2 (45° - \tfrac{1}{2}\phi)$$

The following table gives values of C_e' for varying values of ϕ.

ϕ	C_e'	ϕ	C_e'	ϕ	C_e'	ϕ	C_e'
20°	0.490	30°	0.3333	40°	0.2174	50°	0.1325
25°	0.406	35°	0.2710	45°	0.1718	55°	0.0994

TABLE 177.—DISTRIBUTION OF BASE PRESSURE

NOTE.—R_V = total resultant vertical pressure on base.
A = area of base.
b = width of base (toe to heel).



Base pressure distribution.
(Toe pressures.)

In abutment design resultant pressure should be near center of base to produce even settlement under vibrating loads where soil is compressible.

In retaining-wall design on compressible soils resultant should never be outside of middle third even if toe pressure can be safely increased.

On rock foundations resultant can fall outside of middle, third provided toe pressure does not exceed safe crushing strength of materials.

$$\text{Heel pressure} = \frac{R_V}{A} - \text{toe pressure}.$$

Table 177*A* gives useful data for figuring base pressure under abutments, and the appended explanation (p. 1047) explains in detail the method of figuring base pressure.

TABLE 177A.—USEFUL DATA FOR COMPUTATION OF BASE PRESSURE UNDER ABUTMENTS

Approximate pressure per linear foot length of abutment due to weight of superstructure and live load for different spans

Span, feet	H-15 loading		H-20 loading	
	Dead load, pounds[1]	Live load, pounds[2]	Dead load, pounds[1]	Live load, pounds[2]
Concrete slabs:				
5	500	2,700	600	3,600
10	1,000	2,700	1,300	3,600
15	1,800	2,700	2,300	3,600
20	2.900	2,700	3,600	3,600
25	4,000	2,700	5,100	3,600
Steel I-beam bridges:				
30	3,500	2,700	4,400	3,600
35	4,200	2,700	5,300	3,600
40	5,000	2,700	6,200	3,600
45	5,700	2,800	7,100	3,700
Girders and trusses:				
50	3,500	3,000	4,400	4.000
75	5,600	3,600	7,000	5,400
100	7,800	4,300	9,700	6,500
150	10,400	5,600	13,000	8,500
200	14,000	6,400	17,500	9,600

[1] Deadload equals weight ½ superstructure divided by length of abutment. No fill over slab.

[2] Live load assumes back wheels of trucks directly over abutment with 30 % impact up to 45′ span. Beyond 45′ span uniform live load given in Table 173 is used. One-half total live load divided by length of abutment.

Approximate horizontal earth pressure against back of abutment assuming equivalent live load of 150 lb. and that earth weighs 100 lb. per cubic foot.

$P = 15h^2$ (modified Rankine).

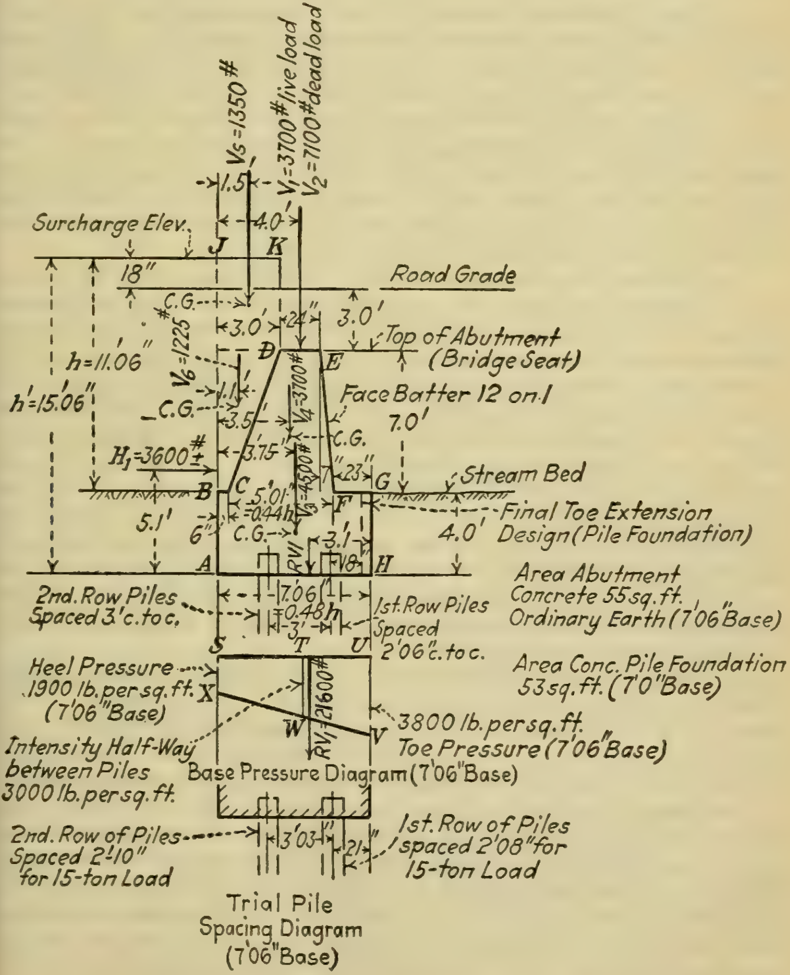
P = total horizontal earth pressure per foot length of abutment applied $\frac{1}{3}$ h above bottom of foundation concrete.

h = vertical distance in feet from bottom of foundation to a level $1\frac{1}{2}'$ above the roadway surface of the bridge floor.

h, in feet	P, in pounds	h, in feet	P, in pounds
5	375	16	3,840
6	540	17	4,335
7	735	18	4,860
8	960	19	5,415
9	1,215	20	6,000
10	1,500	21	6,615
11	1,815	22	7,260
12	2,160	23	7,935
13	2,460	24	8,640
14	2,840	25	9,375
15	3,375	26	10,140
		27	10,935
		28	11,760
		29	12,615
		30	13,500

Base-pressure Computations.—Retaining walls and wings consider horizontal earth pressure. Abutment design for slab bridges less than 20′ spans where the slab is doweled or keyed into the abutment generally consider vertical loads only on the assumption that the slab acts as a brace and neutralizes horizontal earth pressure (see Figs. 69*A* and 69*B*, Chap. IV), but for all spans where the superstructure is designed with expansion and contraction bearings the horizontal earth pressure is considered. The following example illustrates the design of abutments where horizontal as well as vertical pressures are considered.

Example of Base-pressure Computations for Bridge Abutments.
45′ clear span I-beam superstructure.
H-20 loading. Depth floor system 3′ 00″.



Trial design bridge 2, Road 191, New York State.

Section of abutment as shown.

The steps to be gone through are as follows:

1. Trial abutment section.
2. Determine the amount and location of the vertical forces acting on the abutment.
3. Determine the amount and location of horizontal forces acting on the abutment.
4. Determine the amount and location of the resultant pressure on the base.
5. Determine the toe and heel intensity of pressure on the base.
6. Pile spacing if piles are required.
7. Test for horizontal slip.
8. Final abutment section.

1. *Trial Abutment Section.*—Trial dimensions can be closely approximated from standard designs (see Chap. IV). The usual rules for trial dimensions call for a minimum width of abutment at the top of footing course (level with stream bed) of from 0.4 to 0.45h, where h equals the vertical height from the top of the footer course to the road surface, plus 1.5′ equivalent surcharge. The total width of the bottom of the footer course is generally about 0.5h' for ordinary soils, 0.45h' for pile foundations, or gravel and about 0.4h' for hardpan or rock where h' equals the vertical height bottom of footer to road grade plus 1.5′ surcharge.

It is desirable to keep the resultant of all forces near the center of the base of the footer on compressible soils, so that if settlement does occur the abutment will not tip forward and under no circumstances should the resultant fall outside of the middle third of the footer base where the foundation is ordinary soil or piles. To keep the resultant well inside the middle third a face batter of from 1 to 3″ per foot of height is used with a toe footer extension. Where rock or hardpan foundation soil is encountered (non-compressible) it is permissible to permit the resultant to fall at the limit of the middle third of the footer base or slightly outside the middle third so long as the toe pressure does not exceed the safe bearing value of the rock or concrete. These conditions result in a smaller toe extension or in a vertical face. Bridge seat widths and thickness of back walls depend on type of bridge and depth of floor system (see Chap. IV).

2. *Vertical Forces.*—The amount and location of the vertical forces per linear foot of abutment are next determined. These vertical forces consist of the live and dead superstructure loads V_1 and V_2 located at the middle of the bridge seat. From Table 177A, V_1 = 3700 lb., V_2 = 7100 lb. located 4.0′ from the line JA.

The other vertical loads are merely the weight of concrete and earth directly over the base allowing for the equivalent live load surcharge and are located at the centers of gravity of the areas. These forces are determined by getting the areas of the earth load and multiplying by 100 lb. per cubic foot and the areas of concrete and multiplying by 150 lb. per cubic foot. The location of the center of gravities of the various areas are determined as given in Table 170 (p. 1031).

In this way the following earth and concrete forces were determined

V_3 = 4500 lb. located 3.75′ from line JA (area $ABGHA$).
V_4 = 3700 lb. located 3.5′ from line JA (area $CDEFC$).
V_5 = 1350 lb. located 1.5′ from line JA (area $IJKDI$).
V_6 = 1225 lb. located 1.1′ from line JA (area $BIDCB$).

3. *Horizontal Force.*—Horizontal earth pressure by Rankine's formulas can be approximated from Table 177A, which for h' 15′ 06″ = approximately 3600 lb. per linear foot of abutment located $\frac{1}{3}h'$ = 5.1′ above the line AH.

4. *Location and Amount of Vertical Resultant.*—The total amount of the vertical resultant is merely the sum of the vertical forces V_1 to V_6 inclusive, and equals 21,600 lb. RV_1 extreme maximum or 17,900 lb. RV_2 exclusive of superstructure live load.

The location of the resultant is determined by taking moments about the point A as follows:

		Foot-pounds
V_1	3,700 × 4.0′	= 14,800
V_2	7,100 × 4.0	= 28,400
V_3	4,500 × 3.75	= 16,875
V_4	3,700 × 3.5	= 12,950
V_5	1,350 × 1.5	= 2,025
V_6	1,225 × 1.1	= 1,350
HI	3,600 × 5.1	= 18,360
	Max. total	= 94,760
	Total exclusive of live load V_1	= 79,960

The locations of RV_1 and RV_2 are, therefore,

$$\text{Distance } RV_1 \text{ from } A \text{ along line } AH = \frac{94{,}760}{21{,}600} = 4.4'.$$

$$\text{Distance } RV_2 \text{ from } A \text{ along line } AH = \frac{79{,}960}{17{,}900} = 4.5'.$$

That is, for this abutment both conditions of loading give practically the same location of resultant, and it is only necessary to investigate toe pressure for the maximum load condition RV_1.

5. *Intensity of Pressure on Toe and Heel of Abutment Foundation.* The average pressure on the base per square foot equals the total vertical pressure RV_1 (21,600 lb.), divided by the area of the base 7.5′ width × 1′ length $= \frac{21{,}600}{7.5} = 2880$ lb. per square foot $= \frac{RV_1}{A}$.

Twice the average pressure $\frac{2RV_1}{A} = 5760$ lb. per square foot.

The distance of the resultant RV_1 from the toe equals 7.5′ − 4.4′ = 3.1′ and 3.1′ is 41% of the total base width AH(7.5′).

From Table 177 the intensity of the toe pressure where the resultant is 41% of the base width from the toe is 70% of $\frac{2RV_1}{A}$ (5760 lb.). Toe pressure therefore equals 70% of 5760 lb. = 3820 lb. per square foot.

Heel pressure equals 30% of 5760 lb. = 1940 lb.

With these two values the base-pressure diagram is constructed as shown in the figure (p. 1047).

An examination of Table 178 shows that the trial design is safe for all ordinary soils. If coarse gravel, stiff dry clay, hardpan, or rock is encountered the toe extension can be safely reduced 6 to 12″ till the toe pressure rises to a reasonable value for the stiffer soils. If unstable foundation is encountered, piles will be required.

6. *Pile Layout.*—Common pile spacing along single rows varies from 2′ 06″ to 3′ 06″ with 3′ common practice. Distance between rows of piles varies from 2′ 06″ to 4′ with 3′ common practice without special reinforcing in the concrete. Table 179 shows the maximum desirable pile load for a structure of the character at about 15 tons.

The width of base in this abutment limits us to two rows of piles. It is desirable to have the piles in each row carry about the same load per pile to equalize settlement. This is accomplished by a study of the base-pressure diagram with different location and spacing of piles. The front row of piles is never less than 18″ center of pile to toe. Here 21″ will be assumed with 3′ 03″ between the first and second rows of piles. The first row of piles then carries the load area of the base diagram (p. 1047) $TUVW$, which equals,

$$\frac{3000 + 3800}{2} \times 3.3' = 11{,}200 \text{ lb. per foot length of abutment.}$$
$$= 5.6 \text{ tons per foot length of abutment.}$$

Assuming the piles carry all the load and that a load of 15 tons per pile is reasonable, this would require a pile every 2′ 08″ $\left(\frac{15}{5.6} = 2.7'\right)$.

The second row of piles carries the load area

$$STWX = \frac{1900 + 3000}{2} \times 4.2' = 10{,}690 \text{ lb. per foot length}$$
$$= 5.3 \text{ tons per foot length,}$$

which would require a pile every 2′ 10″.

Considering that all earth-pressure formulas are indefinite and that the underlying soil carries some of the load, it would be entirely safe to reduce the toe extension to 18″, place the first row of piles 18″ from the toe spaced 2′ 06″ C. to C. Place the second row 3′ back of the first row and space the piles in the second row 3′ 0″ C. to C., which reduces the cost about $100 to $200.

Resistance to Horizontal Slip.—See Table 180 (p. 1052), using a factor of safety of at least 2 and perferably 3.

Modification of Trial Abutment Section.—Modifications are usually limited to change in toe extension length to produce reasonably high toe pressure for non-compressible hardpan and rock.

Depths of Foundations.—The following tabulation indicates minimum depth of foundations for small bridges.

MINIMUM DEPTH OF BOTTOM CONCRETE FOUNDATIONS BELOW STREAM BED. (SMALL SPAN BRIDGES)

	Abutments	Piers
Ordinary soils	4.0′+	6.0′
Hard pan	3.0′+	4.0′
Shale rock	2.0′+	3.0′
Solid rock	0.5 below surface of solid rock	1.0′

TABLE 178.—SAFE LOAD ON FOUNDATION SOILS IN TONS (2000 LB. PER SQUARE FOOT OF BEARING AREA)

Authority	Quicksand and alluvial silt	Clean, dry sand	Confined sand and fine gravel	Coarse gravel	Ordinary mixture sand and clay	Soft, damp clay	Dry clay	Cemented gravel or hardpan	Soft rock	Hard rock
Baker's "Foundations"	½	2	4	...	.....	1	4	8	5	25
Hool and Johnston	½–1	2–4	4	...	.....	1–2	4–8	8–10	5–10	15–30
Ketchum	.....	3	4	4–5	2	...	3–4	....	8	20
State of Iowa	.....	...	3	3	1.5	...	3	5	7	25
State of Washington	0–½[1]	3	3–3½	4–7	1½–2	0–2	3–5	5–8	8–15	25
New York Building Code	.....	3	4	4	2	1	4			
Division 4, New York State Highway	½	2	3	4–5	2	1	3–4	6–7	8	20

[1] Confined.

TABLE 179.—DESIGN LOAD ON PILES (TONS PER PILE)

Type of structure	Type of pile	Ordinary load	Extreme maximum load
Slab girder or trusses	Timber	12–15	20
Slab girder or trusses	Concrete	25	30
Trestles and viaducts	Timber	15	20
Trestles and viaducts	Concrete	25	30
Arches or continuous girders	Timber[1]	10–12	15
Arches or continuous girders	Concrete[1]	20	25

[1] Piles for these structures to be driven to practical refusal (see p. 1339, Part 2), 25- to 30-ton resistance.

NOTE.—For minimum dimensions of piles see Specifications (p. 1501). Pile spacing generally 3 to 3½′ C. to C. Maximum 4′ without special reinforcing design. Spacing closer than 2½′ worthless. Increase size of footer to get minimum spacing of 2½′.

TABLE 180.—SLIDING FRICTION RESISTANCE

Resistance to sliding varies for different materials and depends on the pressure between the two surfaces. The following data gives common values for the coefficients of friction. To get the resistance to sliding, multiply the proper coefficient by the pressure normal to the plane of contact. A factor of safety of 2 to 3 is usually stipulated for retaining-wall and abutment design.

COEFFICIENTS OF FRICTION[1]

Materials	Coefficients	Materials	Coefficients
Dry masonry on dry masonry	0.6 to 0.7	Masonry on dry clay	0.5 to 0.6
Masonry on masonry with wet mortar	0.75	Masonry on moist clay	0.33
Timber on stone	0.4	Earth on earth	0.25 to 1.0
Iron on stone	0.3 to 0.7	Hard brick on hard brick	0.7
Timber on timber	0.2 to 0.5	Concrete blocks on concrete blocks	0.65

[1] Ketchum's Highway Bridges.

COEFFICIENTS AND ANGLES OF FRICTION BETWEEN EARTH AND OTHER MATERIALS[1]

Materials	$f = \tan \phi$	ϕ
Masonry upon masonry	0.65	33°
Masonry upon wood, with grain	0.60	31°
Masonry upon wood, across grain	0.50	26° 40′
Masonry on dry clay	0.50	26° 40′
Masonry on wet clay	0.33	18° 20′
Masonry on sand	0.40	21° 50′
Masonry on gravel	0.60	31°

[1] Hool & Johnson, Concrete Eng. Handbook.

TABLE 181.—PRESSURE WET CONCRETE AGAINST FORMS

Vertical load, 150 lb. per cubic foot concrete plus 50 lb. live load per square foot.

Horizontal fluid pressure:

85 lb. per cubic foot for mass concrete.

130 lb. per cubic foot for thin walls and slab and girder construction.

NOTE.—For typical standard forms see chapter on Construction and Inspection (pp. 1346 to 1353).

TABLE 182.—COEFFICIENTS OF EXPANSION AND CONTRACTION OF MORTAR AND CONCRETE

Coefficients for steel, 0.0000065

Mortars		Concretes	
Mixture	Coefficient of expansion per degree Fahrenheit	Mixture	Coefficient of expansion per degree Fahrenheit
Neat	0.000,007,83	1:1½:3	0.000,006,77
1:1	0.000,007,43	1:2 :4	0.000,006,60
1:2	0.000,006,00	1:2½:5	0.000,005,58
1:3	0.000,006,05	1:3 :6	0.000,005,37
1:4	0.000,005,94		
1:5	0.000,005,77		

TABLE 183.—TEMPERATURE STRESSES

Stresses are generally figured for 40° above and below mean temperature.

For slabs, beams, etc., with confined ends and no movement of ends the stress per degree change in temperature can be computed by multiplying the modulus of elasticity, Table 171*A*, by the coefficient of expansion and contraction, Table 182, of the material in question.

APPROXIMATE TEMPERATURE STRESS IN CONCRETE BEAMS AND SLABS (CONFINED ENDS)

Change in Temperature, Degrees	Approximate Stress per Square Inch, Pounds
0	0
10	120
20	240
30	360
40	480
50	600

Table 184.—Wire and Wire Gages
Sizes and Weights of Steel Wire
American Steel and Wire Co.'s Gage

Number of gage	Diameters: Fractions of inch	Diameters: Decimals of inch	Diameters: Millimeters	Sectional area, square inch	Weight: Pounds per foot	Weight: Pounds per mile	Number of feet per pound
....	1/2	0.5000	12.70	0.19635	0.6668	3521	1.500
0000000	....	0.4900	12.45	0.18857	0.6404	3381	1.562
....	15/32	0.46875	11.91	0.17257	0.5861	3094	1.706
000000	....	0.4615	11.72	0.16728	0.5681	2999	1.76
....	7/16	0.4375	11.11	0.15033	0.5105	2696	1.959
00000	....	0.4305	10.93	0.14556	0.4943	2610	2.023
....	13/32	0.40625	10.32	0.12962	0.4402	2324	2.272
0000	....	0.3938	10.00	0.12180	0.4136	2184	2.418
....	3/8	0.3750	9.525	0.11045	0.3751	1980	2.666
000	....	0.3625	9.2075	0.10321	0.3505	1851	2.853
....	11/32	0.34375	8.731	0.092806	0.3152	1664	3.173
00	....	0.3310	8.407	0.086049	0.2922	1543	3.422
....	5/16	0.3125	7.938	0.076699	0.2605	1375	3.839
0	....	0.3065	7.785	0.073782	0.2506	1323	3.991
1	....	0.2830	7.188	0.062902	0.2136	1128	4.681
....	9/32	0.28125	7.144	0.062126	0.2110	1114	4.74
2	....	0.2625	6.668	0.054119	0.1838	970.4	5.441
....	1/4	0.2500	6.350	0.049087	0.1667	880.2	5.999
3	......	0.2437	6.190	0.046645	0.1584	836.4	6.313
4	....	0.2253	5.723	0.039867	0.1354	714.8	7.386
....	7/32	0.21875	5.556	0.037583	0.1276	673.9	7.835
5	....	0.2070	5.258	0.033654	0.1143	603.4	8.750
6	....	0.1920	4.877	0.028953	0.09832	519.2	10.17
....	3/16	0.1875	4.763	0.027612	0.09377	495.1	10.66
7	....	0.1770	4.496	0.024606	0.08356	441.2	11.97
8	....	0.1620	4.115	0.020612	0.07000	369.6	14.29
....	5/32	0.15625	3.969	0.019175	0.06512	343.8	15.36
9	....	0.1483	3.767	0.017273	0.05866	309.7	17.05
10	....	0.1350	3.429	0.014314	0.04861	256.7	20.57
....	1/8	0.125	3.175	0.012272	0.04168	220.0	24.00
11	....	0.1205	3.061	0.011404	0.03873	204.5	25.82
12	....	0.1055	2.68	0.0087417	0.02969	156.7	33.69
....	3/32	0.09375	2.381	0.0069029	0.02344	123.8	42.66
13	....	0.0915	2.324	0.0065755	0.02233	117.9	44.78
14	....	0.0800	2.032	0.0050266	0.01707	90.13	58.58
15	....	0.0720	1.829	0.0040715	0.01383	73.01	72.32
16	1/16	0.0625	1.588	0.0030680	0.01042	55.01	95.98
17	....	0.0540	1.372	0.0022902	0.007778	41.07	128.60
18	....	0.0475	1.207	0.0017721	0.006018	31.77	166.20
19	....	0.0410	1.041	0.0013203	0.004484	23.67	223.00
20	....	0.0348	0.8839	0.00095115	0.003230	17.05	309.60
21	....	0.0317	0.8052	0.00078924	0.002680	14.15	373.10
....	1/32	0.03125	0.7938	0.00076699	0.002605	13.75	383.00
22	....	0.0286	0.7264	0.00064242	0.002182	11.52	458.40
23	....	0.0258	0.6553	0.00052279	0.001775	9.374	563.30
24	....	0.0230	0.5842	0.00041548	0.001411	7.45	708.70

For iron wire multiply columns 6 and 7 by 0.98.
For copper wire multiply columns 6 and 7 by 1.12.
For other wire gages see next page.

Note.—Tables 184 and 185 from American Civil Engineers' Pocketbook. John Wiley & Sons Co.

TABLE 184A.—COMPARISON OF STANDARD GAGES

Number of gage	Thickness in decimals of an inch						
	Birmingham	Browne & Sharpe	United States Standard Plate Iron and Steel	British Imperial	American Steel & Wire	Trenton Iron Co.	Stubs steel wire
0000000	......	....	0.500	0.500	0.4900		
000000	......	0.58	0.46875	0.464	0.4615		
00000	0.500	0.5165	0.4375	0.432	0.4305	0.45	
0000	0.454	0.46	0.40625	0.400	0.3938	0.40	
000	0.425	0.40964	0.375	0.372	0.3625	0.35	
00	0.380	0.3648	0.34375	0.348	0.3310	0.33	
0	0.340	0.32486	0.3125	0.324	0.3065	0.305	
1	0.300	0.2893	0.28125	0.300	0.2830	0.285	0.227
2	0.284	0.25763	0.265625	0.276	0.2625	0.265	0.219
3	0.259	0.22942	0.25	0.252	0.2437	0.245	0.212
4	0.238	0.20431	0.234375	0.232	0.2253	0.225	0.207
5	0.220	0.18194	0.21875	0.212	0.2070	0.205	0.204
6	0.203	0.16202	0.203125	0.192	0.1920	0.190	0.201
7	0.180	0.14428	0.1875	0.176	0.1770	0.175	0.199
8	0.165	0.12849	0.171875	0.160	0.1620	0.160	0.197
9	0.148	0.11443	0.15625	0.144	0.1483	0.145	0.194
10	0.134	0.10189	0.140625	0.128	0.1350	0.130	0.191
11	0.120	0.090742	0.125	0.116	0.1205	0.1175	0.188
12	0.109	0.080808	0.109375	0.104	0.1055	0.1050	0.185
13	0.095	0.071961	0.09375	0.092	0.0915	0.0925	0.182
14	0.083	0.064084	0.078125	0.080	0.0800	0.0800	0.180
15	0.072	0.057068	0.0703125	0.072	0.0720	0.0700	0.178
16	0.065	0.05082	0.0625	0.064	0.0625	0.0610	0.175
17	0.058	0.045257	0.05625	0.056	0.0540	0.0525	0.172
18	0.049	0.040303	0.05	0.048	0.0475	0.0450	0.168
19	0.042	0.03589	0.04375	0.040	0.0410	0.0400	0.164
20	0.035	0.031961	0.0375	0.036	0.0348	0.0350	0.161
21	0.032	0.028462	0.034375	0.032	0.03175	0.0310	0.157
22	0.028	0.025347	0.03125	0.028	0.0286	0.0280	0.155
23	0.025	0.022571	0.028125	0.024	0.0258	0.0250	0.153
24	0.022	0.0201	0.025	0.022	0.0230	0.0225	0.151
25	0.020	0.0179	0.021875	0.020	0.0204	0.0200	0.148
26	0.018	0.01594	0.01875	0.018	0.0181	0.0180	0.146
27	0.016	0.014195	0.0171875	0.0164	0.0173	0.0170	0.143
28	0.014	0.012641	0.015625	0.0148	0.0162	0.0160	0.139
29	0.013	0.011257	0.0140625	0.0136	0.0150	0.0150	0.134
30	0.012	0.010025	0.0125	0.0124	0.0140	0.0140	0.127
31	0.010	0.008928	0.0109375	0.0116	0.0132	0.0130	0.120
32	0.009	0.00795	0.01015625	0.0108	0.0128	0.0120	0.115
33	0.008	0.00708	0.009375	0.0100	0.0118	0.0110	0.112
34	0.007	0.006304	0.00859375	0.0092	0.0104	0.0100	0.110
35	0.005	0.005614	0.0078125	0.0084	0.0095	0.0095	0.108
36	0.004	0.005	0.00703125	0.0076	0.0090	0.0090	0.106
37	......	0.004453	0.006640625	0.0068	0.0085	0.0085	0.103
38	......	0.003965	0.00625	0.0060	0.0080	0.0080	0.101
39	......	0.003531	....	0.0052	0.0075	0.0075	0.099
40	......	0.003144	....	0.0048	0.0070	0.0070	0.097

In the U. S. Standard, the numbers correspond to the weight in ounces per square feet and an equal number of 640ths of an inch in thickness.

TABLE 184*B*.—NATIONAL STEEL FABRIC STANDARD STYLES

For buildings and other structures—cement gun work, beam wrapping, temperature reinforcement, canal lining, levee work, concrete pipe, etc.

Suggested uses	Style	Spacing, inches		Gage of wire		Section area square inches per linear foot		Weight per 100 sq. ft.
		Long.	Trans.	Long.	Trans.	Long.	Trans.	
Cement, gun work, composition, floors, etc.	AA 1414	2	2	14	14	0.030	0.030	21.1
	AA 1212	2	2	12	12	0.052	0.052	36.8
	BB 1212	4	4	12	12	0.026	0.026	18.7
	BB 1010	4	4	10	10	0.043	0.043	30.6
Cement, gun work, levee, lining, etc.....	BB 88	4	4	8	8	0.062	0.062	44.1
	BB 66	4	4	6	6	0.087	0.087	61.9
	BB 55	4	4	5	5	0.101	0.101	72.0
	BB 44	4	4	4	4	0.120	0.120	85.3
Temperature, reinforcement, etc........	CC 1212	6	6	12	12	0.017	0.017	12.7
	CC 1111	6	6	11	11	0.023	0.023	16.5
	CC 1010	6	6	10	10	0.029	0.029	20.7
	CC 99	6	6	9	9	0.035	0.035	25.1
Slab, reinforcement, fireproofing, retaining walls, etc.	BH 1212	4	16	12	12	0.026	0.007	11.8
	BH 1012	4	16	10	12	0.043	0.007	17.9
	BH 912	4	16	9	12	0.052	0.007	21.1
	BH 812	4	16	8	12	0.062	0.007	24.7
	BH 711	4	16	7	11	0.074	0.008	29.7
	BH 610	4	16	6	10	0.087	0.011	35.2
	BH 510	4	16	5	10	0.101	0.011	40.4
	BH 49	4	16	4	9	0.120	0.013	47.9
	BH 38	4	16	3	8	0.140	0.015	56.1
	BH 28	4	16	2	8	0.162	0.015	64.3
	BH [illegible]	[illegible]	16	[illegible]	[illegible]	0.180	0.018	74.8

Slab reinforcement, fireproofing, driveways and walks, etc.	BF 1212	4	12	12	12	0.026	0.009	12.6
	BF 1112	4	12	11	12	0.034	0.009	15.5
	BF 1012	4	12	10	12	0.043	0.009	18.6
	BF 912	4	12	9	12	0.052	0.009	21.8
	BF 812	4	12	8	12	0.062	0.009	25.5
	BF 712	4	12	7	12	0.074	0.009	29.8
	BF 611	4	12	6	11	0.087	0.011	35.5
	BF 610	4	12	6	10	0.087	0.014	36.5
	BF 510	4	12	5	10	0.101	0.014	41.6
	BF 49	4	12	4	9	0.120	0.017	49.4
Beam wrapping, fireproofing, etc.	BD 1212	4	8	12	12	0.026	0.013	14.1
	BD 1112	4	8	11	12	0.034	0.013	17.0
	BD 1012	4	8	10	12	0.043	0.013	20.2
Concrete pipe, etc.	BD 912	4	8	9	12	0.052	0.013	23.4
	BD 812	4	8	8	12	0.062	0.013	27.0
	BD 712	4	8	7	12	0.074	0.013	31.3
Slab reinforcement, fireproofing, etc.	TH 610	3	16	6	10	0.116	0.011	45.1
	TH 510	3	16	5	10	0.035	0.011	51.8
	TH 49	3	16	4	9	0.160	0.013	61.4
	TH 38	3	16	3	8	0.187	0.015	72.0
	TH 28	3	16	2	8	0.217	0.015	82.6
	TH 17	3	16	1	7	0.252	0.018	96.2
	TH 06	3	16	0	6	0.295	0.022	112.9

Furnished with plain or galvanized finish; unless ordered galvanized, plain wire will be furnished.

Width, 56 or 60″ C-C outside main wires, 1″ overhang; total width, 58 or 62″ for 4″ spacing of main wires.

Width, 54 or 60″ C-C outside main wires, 1″ overhang; total width, 56 or 62″ for 6″ spacing of main wires.

Length of rolls, 125 to 300 lin. ft. depending on the weight of style selected. It is recommended that styles with longitudinal wires of No. 3 gage or heavier be furnished in flat sheets.

Wire Fabric

TABLE 184C.—AREA IN SQUARE INCHES PER FOOT OF WIDTH FOR VARIOUS SPACING OF WIRES

Wire			Center to center spacing												
Gage W & M[1]	Diameter, inches	Area, square inches	2″	3″	4″	5″	6″	7″	8″	9″	10″	12″	14″	16″	18″
6–0	0.4615	0.16728	1.004	0.669	0.502	0.402	0.335	0.287	0.251	0.223	0.201	0.167	0.143	0.125	0.112
5–0	0.4305	0.14556	0.874	0.582	0.437	0.349	0.291	0.250	0.218	0.194	0.175	0.146	0.125	0.109	0.097
4–0	0.3938	0.12180	0.731	0.487	0.365	0.292	0.244	0.209	0.183	0.162	0.146	0.122	0.104	0.091	0.081
3–0	0.3625	0.10321	0.619	0.413	0.310	0.248	0.206	0.177	0.155	0.138	0.124	0.103	0.088	0.077	0.069
2–0	0.3310	0.08605	0.516	0.344	0.258	0.207	0.172	0.148	0.129	0.115	0.103	0.086	0.074	0.065	0.057
0	0.3065	0.07378	0.443	0.295	0.221	0.177	0.148	0.126	0.111	0.099	0.089	0.074	0.063	0.056	0.049
1	0.2830	0.06290	0.377	0.252	0.189	0.151	0.126	0.107	0.094	0.084	0.075	0.063	0.054	0.047	0.041
2	0.2625	0.05411	0.325	0.217	0.162	0.130	0.108	0.093	0.081	0.072	0.065	0.054	0.047	0.041	0.036
3	0.2437	0.04664	0.280	0.187	0.140	0.112	0.093	0.080	0.070	0.062	0.056	0.047	0.040	0.035	0.031
4	0.2253	0.03986	0.239	0.160	0.120	0.096	0.080	0.068	0.059	0.053	0.048	0.040	0.034	0.030	0.026
5	0.2070	0.03365	0.202	0.135	0.101	0.081	0.067	0.058	0.050	0.045	0.040	0.034	0.029	0.025	0.022
6	0.1920	0.02895	0.174	0.116	0.087	0.069	0.058	0.050	0.043	0.039	0.035	0.029	0.025	0.022	0.019
7	0.1770	0.02460	0.148	0.098	0.074	0.059	0.049	0.042	0.037	0.033	0.030	0.025	0.021	0.018	0.016
7½	0.1695	0.02256	0.135	0.090	0.068	0.054	0.045	0.039	0.034	0.030	0.027	0.023	0.019	0.017	0.015
8	0.1620	0.02061	0.124	0.082	0.062	0.049	0.041	0.035	0.031	0.027	0.025	0.021	0.018	0.015	0.014
9	0.1483	0.01727	0.104	0.069	0.052	0.041	0.035	0.029	0.026	0.023	0.021	0.017	0.015	0.013	0.011
9½	0.1416	0.01575	0.095	0.063	0.047	0.038	0.032	0.027	0.024	0.021	0.019	0.016	0.014	0.012	0.010
10	0.1350	0.01431	0.086	0.057	0.043	0.034	0.029	0.025	0.021	0.019	0.017	0.014	0.012	0.011	0.009
11	0.1205	0.01140	0.068	0.045	0.034	0.027	0.023	0.019	0.017	0.015	0.014	0.011	0.009	0.008	0.007
11½	0.1130	0.01002	0.060	0.040	0.030	0.024	0.020	0.017	0.015	0.013	0.012	0.010	0.009	0.008	0.007
12	0.1055	0.00874	0.052	0.035	0.026	0.021	0.017	0.015	0.013	0.012	0.010	0.009	0.007	0.006	0.006
12½	0.0985	0.00762	0.046	0.030	0.023	0.018	0.015	0.013	0.011	0.010	0.009	0.007	0.007	0.006	0.005
13	0.0915	0.00657	0.040	0.027	0.020	0.016	0.013	0.011	0.010	0.009	0.008	0.006	0.006	0.005	0.004
14	0.0800	0.00502	0.030	0.020	0.015	0.012	0.010	0.009	0.008	0.007	0.006	0.005	0.004	0.004	0.003

TABLE 184D.—APPROXIMATE WEIGHTS PER 100 SQ. FT.

Longitudinal wires

Gage of wires	Center to center spacing of longitudinal wires, in inches						
	2″	3″	4″	5″	6″	10″	12″
6–0	352.22	238.60	181.79	147.71	124.98	79.53	68.17
5–0	306.47	207.61	158.18	128.52	108.75	69.20	59.32
4–0	256.43	173.71	132.35	107.54	90.99	57.90	49.63
3–0	217.31	147.21	112.16	91.13	77.11	49.07	42.06
2–0	181.16	122.72	93.50	75.97	64.28	40.91	35.06
0	155.37	105.25	80.19	65.16	55.13	35.08	30.07
1	132.43	89.71	68.35	55.54	46.99	29.90	25.63
2	113.96	77.20	58.82	47.79	40.44	25.73	22.06
3	98.21	66.53	50.69	41.18	34.85	22.18	19.01
4	83.95	56.87	43.33	35.20	29.79	18.96	16.25
5	70.87	48.01	36.58	29.72	25.15	16.00	13.72
6	60.96	41.29	31.46	25.56	21.63	13.76	11.80
7	51.81	35.10	26.74	21.73	18.38	11.70	10.03
8	43.40	29.40	22.40	18.20	15.40	9.80	8.40
9	36.37	24.64	18.77	15.25	12.91	8.21	7.04
10	30.14	20.42	15.56	12.64	10.69	6.81	5.83
11	24.01	16.27	12.39	10.07	8.52	5.42	4.65
12	18.41	12.47	9.50	7.72	6.53	4.16	3.56
13	13.84	9.38	7.15	5.81	4.91	3.13	2.68
14	10.58	7.17	5.46	4.44	3.76	2.39	2.05

Transverse wires

Gage of wires	Center to center spacing of transverse wires, in inches					
	2″	4″	6″	8″	12″	16″
0	155.37	77.69	51.79	38.84	25.89	19.42
1	132.43	66.22	44.14	33.11	22.07	16.55
2	113.96	56.98	37.98	28.49	18.99	14.24
3	98.21	49.10	32.74	24.55	16.37	12.28
4	83.95	41.97	27.98	20.99	13.99	10.49
5	70.87	35.43	23.61	17.72	11.81	8.86
6	69.96	30.48	20.32	15.24	10.16	7.62
7	51.81	25.90	17.27	12.95	8.63	6.48
8	43.40	21.70	14.47	10.85	7.23	5.43
9	36.37	18.18	12.12	9.09	6.06	4.55
10	30.14	15.07	10.05	7.53	5.02	3.77
11	24.01	12.01	8.00	6.00	4.00	3.00
12	18.41	9.20	6.13	4.60	3.07	2.30
13	13.84	6.92	4.61	3.46	2.31	1.73
14	10.58	5.29	3.53	2.65	1.76	1.32

Above weights to be used in computing the weights per 100 sq. ft. of National steel fabric.

Example.—Weight per 100 sq. ft. of 6 by 12″ fabric with longitudinal wires No. 0, transverse wires No. 6. Add to weight of longitudinal wire No. 0 spaced 6″ (55.13 lb.), the weight of transverse wire No. 6 spaced 12″ (10.16 lb.), making total of 65.29 lb. per 100 sq. ft.

TABLE 185.—WEIGHTS OF EXPANDED METAL

Trade Catalogue Weights

1

Gauge	Size Mesh	Weight in Pounds per Sq. Ft.
10	$3\frac{1}{2}'' \times 7''$	0.68
12	$3\frac{1}{2}'' \times 7''$	0.54
10	$2\frac{1}{2}'' \times 5''$	0.86
12	$2\frac{1}{2}'' \times 5''$	0.68
14	$2\frac{1}{2}'' \times 5''$	0.48
16	$2\frac{1}{2}'' \times 5''$	0.37
16	$1\frac{1}{2}'' \times 3''$	0.40
16	$1'' \times 2''$	0.50
15	$1'' \times 2''$	0.57
14	$1'' \times 2''$	0.64
13	$1'' \times 2''$	0.78

2

Mesh	Gauge (Stubs)	Strand Standard or Extra	Section Area per Foot of Width	Weight per Sq. Ft.	Size of Standard Sheets	No. of Sheets in Bundle	No. of Sq. Ft. in 8′ Bundle
$\frac{1}{2}''$	No. 18	Standard	0.209	.74	3′ or 6′×8′	5	120
$\frac{3}{4}''$	13	"	0.225	.80	6′ ×8′ or 12′	5	240
$1\frac{1}{2}''$	12	"	0.207	.70	4′ ×8′ or 12′	5	160
2 "	12	"	0.166	.56	5′ ×8′ or 12′	5	200
3 "	16	"	0.083	.28	6′ ×8′ or 12′	10	480
3 "	10	Light	0.148	.50	6′ ×8′ or 12′	5	240
3 "	10	Standard	0.178	.60	6′ ×8′ or 12′	5	240
3 "	10	Heavy	0.267	.90	4′ ×8′ or 12′	5	160
3 "	10	Ex "	0.356	1.20	6′ ×8′ or 12′	3	144
3 "	6	Standard	0.400	1.38	5′ ×8′ or 12′	3	120
3 "	6	Heavy	0.600	2.07	5′ ×8′ or 12′	3	120
4 "	16	Old Style	0.093	.42	$4\frac{1}{2}'$×8′ or 9′	6	216

Weight and Sectional Area Taken from I. C. S. Handbook

U. S. Standard Gauge	Size Mesh	Sectional Area in Sq. In. per Foot of Width	Weight in Pounds per Sq. Ft.
18	$\frac{1}{2}'' \times 1\frac{1}{2}''$	0.203	0.69
12	$\frac{3}{4}'' \times 2''$	0.253	0.86
12	$1\frac{1}{2}'' \times 3''$	0.188	0.64
16	$2\frac{1}{4}'' \times 6''$	0.087	0.29
16	$3'' \times 8''$	0.130	0.44
16	$3'' \times 8''$	0.059	0.20
12	$3'' \times 8''$	0.109	0.37
10	$3'' \times 8''$	0.162	0.55
10	$3'' \times 8''$	0.243	0.81
10	$3'' \times 8''$	0.324	1.07
7	$3'' \times 8''$	0.400	1.36
4	$6'' \times 12''$	0.245	0.84
4	$6'' \times 12''$	0.368	1.26

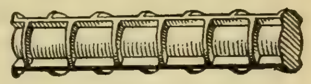
NOTE. — Expanded metal for small culverts is generally specified as weighing a certain number of pounds per square foot and having a mesh approximately the size shown on the plans.

TABLE 186.—TABLE OF ROUND AND SQUARE BAR WEIGHTS[1]

Round Bars			Plain Square Bars and Twisted Square Bars		
Diameter	Area	Weight	Dimension	Area	Weight
$\frac{1}{4}$	**.0491**	**.167**	$\frac{1}{4}$	.0625	.212
$\frac{5}{16}$	.0767	.261	$\frac{5}{16}$	.0977	.332
$\frac{3}{8}$	**.1104**	**.376**	$\frac{3}{8}$	.1406	.478
$\frac{7}{16}$	.1503	.511	$\frac{7}{16}$	.1914	.651
$\frac{1}{2}$	**.1963**	**.668**	$\frac{1}{2}$	**.2500**	**.850**
$\frac{9}{16}$	.2485	.845	$\frac{9}{16}$	.3164	1.076
$\frac{5}{8}$	**.3068**	**1.043**	$\frac{5}{8}$	.3906	1.328
$\frac{11}{16}$	.3712	1.262	$\frac{11}{16}$	.4727	1.607
$\frac{3}{4}$	**.4418**	**1.502**	$\frac{3}{4}$	.5625	1.913
$\frac{13}{16}$	.5185	1.763	$\frac{13}{16}$	.6602	2.245
$\frac{7}{8}$	**.6013**	**2.044**	$\frac{7}{8}$	.7656	2.603
$\frac{15}{16}$	.6903	2.347	$\frac{15}{16}$	.8789	2.988
1	**.7854**	**2.670**	1	**1.0000**	**3.400**
$1\frac{1}{8}$	.9940	3.380	$1\frac{1}{8}$	**1.2656**	**4.303**
$1\frac{1}{4}$	1.2272	4.172	$1\frac{1}{4}$	**1.5625**	**5.313**
$1\frac{3}{8}$	1.4849	5.049	$1\frac{3}{8}$	1.8906	6.428
$1\frac{1}{2}$	1.7671	6.008	$1\frac{1}{2}$	2.2500	7.650

[1] Stock sizes of 1926 are printed in bold-face type.

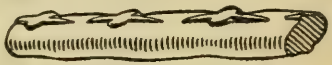
Ransome Bar.



Kahn Cup Bar.

Corrugated Bars.

Diamond Bar.



Thacher Bar.

Diameters expressed in inches. Areas expressed in square inches.
Weights expressed in pounds per foot of length.
The twisted square bar is known as the Ransome Bar.
Corrugated bar weights very closely approximate the weights given for the plain bars. See makers catalogue for any special brand.

Steel Beams.—Tables 187 and 188 give data on the strength of steel beams. To avoid objectionable deflection in bridge floors the following specifications for minimum depth of stringers, girders and trusses indicate the desirable minimum depths of steel beams.

Depth Ratios of Steel Floor and Truss Members[1]

Trusses preferably not less than $\frac{1}{10}$ of span
Plate girders preferably not less than $\frac{1}{12}$ of span
Rolled beams used as girders preferably not less than $\frac{1}{20}$ of span

If less depth is used section area to be increased so that deflection is not greater than if these limiting ratios had been used.

[1] American Soc. Specifications 1925.

TABLE 187*A*.—PROPERTIES OF CAMBRIA STANDARD I-BEAMS[1]

Depth of Beam	Weight per Foot	Area of Section	Thickness of Web	Width of Flange	For Fiber Stress of 12,500 lbs. per Sq. In. for Bridges
Inches	Pounds	Sq. Inches	Inch	Inches	Coefficient of Strength
3	5.50	1.63	.17	2.33	13,790
3	6.50	1.91	.26	2.42	14,950
3	7.50	2.21	.36	2.52	16,180
4	7.50	2.21	.19	2.66	24,850
4	8.50	2.50	.26	2.73	26,480
4	9.50	2.79	.34	2.81	28,110
4	10.50	3.09	.41	2.88	29,750
5	9.75	2.87	.21	3.00	40,300
5	12.25	3.60	.36	3.15	45,390
5	14.75	4.34	.50	3.29	50,490
6	12.25	3.61	.23	3.33	60,520
6	14.75	4.34	.35	3.45	66,610
6	17.25	5.07	.47	3.57	72,740
7	15.00	4.42	.25	3.66	86,260
7	17.50	5.15	.35	3.76	93,290
7	20.00	5.88	.46	3.87	100,430
8	18.00	5.33	.27	4.00	118,490
8	20.25	5.96	.35	4.08	125,400
8	22.75	6.69	.44	4.17	133,570
8	25.25	7.43	.53	4.26	141,740
9	21.00	6.31	.29	4.33	157,260
9	25.00	7.35	.41	4.45	170,260
9	30.00	8.82	.57	4.61	188,640
9	35.00	10.29	.73	4.77	207,020
10	25.00	7.37	.31	4.66	203,500
10	30.00	8.82	.45	4.80	223,630
10	35.00	10.29	.60	4.95	244,050
10	40.00	11.76	.75	5.10	264,480
12	31.50	9.26	.35	5.00	299,740
12	35.00	10.29	.44	5.09	317,030
12	40.00	11.76	.56	5.21	341,540

[1] 1912 Standards.

TABLE 187.—*Continued*

Depth of Beam	Weight per Foot	Area of Section	Thickness of Web	Width of Flange	For Fiber Stress of 12,500 lbs. per Sq. In. for Bridges
Inches	Pounds	Sq. Inches	Inch	Inches	Coefficient of Strength
15	42.00	12.48	.41	5.50	490,840
15	45.00	13.24	.46	5.55	506,490
15	50.00	14.71	.56	5.65	537,130
15	55.00	16.18	.66	5.75	567,770
15	60.00	17.65	.75	5.84	598,410
18	55.00	15.93	.46	6.00	736,620
18	60.00	17.65	.56	6.10	779,440
18	65.00	19.12	.64	6.18	816,200
18	70.00	20.59	.72	6.26	852,970
20	65.00	19.08	.50	6.25	974,600
20	70.00	20.59	.58	6.33	1,016,490
20	75.00	22.06	.65	6.40	1,057,340
24	80.00	23.32	.50	7.00	1,449,460
24	85.00	25.00	.57	7.07	1,505,430
24	90.00	26.47	.63	7.13	1,554,450
24	95.00	27.94	.69	7.19	1,603,470
24	100.00	29.41	.75	7.25	1,652,490

Explanation of the coefficient of strength in the above table and examples showing use in practice.

The coefficient of strength for each sized beam represents the maximum uniformly distributed load, in pounds, that will produce a fiber stress not exceeding 12,500 lb. per square inch multiplied by the span in feet.

If the load to be investigated is a concentrated load it must be changed to an equivalent uniform load in order to use the values given. This is done by multiplying the concentrated load by 2.

Example.—Suppose that it is required to determine the size I-beam that will carry a 40,000-lb. load in the center of a 15′ span and a uniformly distributed load of 20,000 lb. The coefficient of resistance for the concentrated load will be 2(40,000) × 15 = 1,200,000

Uniform load 20,000 × 15 = 300,000

1,500,000

The required beam must have a coefficient of resistance of 1,500,000 plus the coefficient due to its own weight. A 24″ beam weighing 90 lb. per foot has a coefficient of 1,554,450.

The beam weighs 90 × 15 = 1350. The coefficient for the beam weight is 1350 × 15 = 20,250, which deducted from 1,554,450 gives a coefficient of 1,534,200, which is slightly greater than required and is safe.

TABLE 187*B*.—BETHLEHEM STAND-

Section number	Depth of beam, inches	Weight, lbs. per foot	Area of section, square inches	Thickness of web, inches	Width of flange, inches	Axis XX* Moment of inertia I	Axis XX* Radius of gyration r	Axis XX* Section modulus S
B30	30 1/8	129.0	37.52	.580	10.530	5,566.5	12.18	369.6
	30	121.0	35.36	.550	10.500	5,213.6	12.14	347.6
	29 7/8	115.0	33.50	.530	10.480	4,886.8	12.08	327.1
B28	28 1/8	113.0	32.98	.540	10.030	4,285.5	11.40	304.8
	28	106.0	30.93	.510	10.000	3,993.8	11.36	285.3
	27 7/8	100.0	29.18	.490	9.980	3,723.4	11.30	267.1
B26	26 1/8	98.0	28.47	.500	9.530	3,200.9	10.60	245.1
	26	91.0	26.55	.470	9.500	2,962.8	10.56	227.9
	25 7/8	85.5	24.89	.450	9.480	2,742.2	10.50	211.9
B24b	24 3/32	104.5	30.63	.550	9.775	2,967.7	9.84	246.4
	24	99.5	29.15	.525	9.750	2,811.7	9.82	234.3
	23 29/32	95.5	27.79	.505	9.730	2,663.1	9.79	222.8
B24a	24	84.5	24.80	.460	9.250	2,381.9	9.80	198.5
B24	24	83.0	24.59	.520	9.130	2,240.9	9.55	186.7
	24	73.5	21.47	.390	9.000	2,091.0	9.87	174.3
B22	22 1/8	71.5	20.88	.420	8.535	1,705.2	9.04	154.2
	22 1/16	68.5	20.04	.405	8.520	1,629.3	9.02	147.7
	22	65.5	19.08	.385	8.500	1,549.5	9.01	140.9
B20a	20	82.0	24.17	.570	8.890	1,559.8	8.03	156.0
	20	73.0	21.37	.430	8.750	1,466.5	8.28	146.7
B20	20	69.0	20.26	.520	8.145	1,268.9	7.91	126.9
	20	64.5	18.86	.450	8.075	1,222.1	8.05	122.2
	20	59.5	17.36	.375	8.000	1,172.2	8.22	117.2
B18a	18 1/8	74.0	21.61	.440	8.770	1,238.0	7.57	136.6
	18	69.0	20.20	.420	8.750	1,142.5	7.52	126.9
	17 7/8	64.5	18.79	.400	8.730	1,048.5	7.47	117.3
B18	18	59.0	17.40	.495	7.675	883.3	7.12	98.1
	18	54.5	15.87	.410	7.590	842.0	7.28	93.6
	18	52.0	15.24	.375	7.555	825.0	7.36	91.7
	18	49.0	14.25	.320	7.500	798.3	7.48	88.7
B15b	15	71.5	20.95	.520	7.500	796.2	6.16	106.2
B15a	15	64.0	18.81	.605	7.195	664.9	5.95	88.6
	15	54.5	15.88	.410	7.000	610.0	6.20	81.3
B15	15	46.0	13.52	.440	6.810	484.8	5.99	64.6
	15	41.0	12.02	.340	6.710	456.7	6.16	60.9
	15	38.5	11.27	.290	6.660	442.6	6.27	59.0
B12a	12	36.5	10.61	.310	6.300	269.2	5.04	44.9
B12	12	32.0	9.44	.335	6.205	228.5	4.92	38.1
	12	28.5	8.42	.250	6.120	216.2	5.07	36.0
B10	10	28.5	8.34	.390	5.990	134.6	4.02	26.9
	10	23.5	6.94	.250	5.850	122.9	4.21	24.6
B9	9	24.0	7.04	.365	5.555	92.1	3.62	20.5
	9	20.5	6.01	.250	5.440	85.1	3.76	18.9
B8	8	19.5	5.78	.325	5.325	60.6	3.24	15.1
	8	17.5	5.18	.250	5.250	57.4	3.33	14.3

W = Safe load in pounds, uniformly distributed, including weight of beam.
L = Span, in feet.
M = Moment of forces, in foot pounds.
f = Allowable fiber stress, in lbs. per square inch.
S = Section modulus about axis XX.

* Axis XX parallel to flange. Axis YY parallel to web.

ARD I-BEAMS (1926 STANDARD)

Coefficients of strength			Maximum safe shear on web, in pounds	Axis YY*			Section number
For fiber stress of 16,000 lbs. per sq. in. Usual building code requirement C	For fiber stress of 12,000 lbs. per sq. in. For moving loads C'	For fiber stress of 18,000 lbs. per sq. in. For quiescent loads C''		Moment of inertia I'	Radius of gyration r'	Section modulus S'	
3,943,000	2,957,000	4,435,000	119,100	177.5	2.18	33.7	
3,707,000	2,781,000	4,171,000	107,300	164.3	2.16	31.3	B30
3,489,000	2,617,000	3,925,000	99,500	151.8	2.13	29.0	
3,251,000	2,438,000	3,658,000	103,300	142.3	2.08	28.4	
3,043,000	2,282,000	3,423,000	92,300	130.9	2.06	26.2	B28
2,849,000	2,137,000	3,205,000	85,000	120.2	2.03	24.1	
2,614,000	1,961,000	2,941,000	88,500	110.6	1.97	23.2	
2,431,000	1,823,000	2,735,000	78,300	100.9	1.95	21.2	B26
2,260,000	1,695,000	2,543,000	71,600	91.6	1.92	19.3	
2,628,000	1,971,000	2,957,000	104,300	132.9	2.08	27.2	
2,499,000	1,874,000	2,812,000	95,900	124.8	2.07	25.6	B24b
2,376,000	1,782,000	2,673,000	89,300	117.1	2.05	24.1	
2,117,000	1,588,000	2,382,000	75,100	91.1	1.92	19.7	B24a
1,992,000	1,494,000	2,241,000	93,100	78.0	1.78	17.1	B24
1,859,000	1,394,000	2,091,000	54,000	74.4	1.86	16.5	
1,645,000	1,233,000	1,850,000	62,500	65.8	1.78	15.4	
1,576,000	1,182,000	1,773,000	58,200	62.3	1.76	14.6	B22
1,503,000	1,127,000	1,690,000	52,600	58.8	1.76	13.8	
1,664,000	1,248,000	1,872,000	102,400	79.9	1.82	18.0	B20a
1,564,000	1,173,000	1,760,000	64,900	75.9	1.88	17.3	
1,354,000	1,015,000	1,523,000	88,200	51.2	1.59	12.6	
1,304,000	977,700	1,467,000	69,400	49.8	1.62	12.3	B20
1,250,000	937,700	1,407,000	50,000	48.3	1.66	12.1	
1,458,000	1,093,000	1,640,000	66,100	82.9	1.96	18.9	
1,354,000	1,016,000	1,523,000	60,800	75.6	1.93	17.3	B18a
1,251,000	938,000	1,407,000	55,600	68.4	1.91	15.7	
1,047,000	785,200	1,178,000	78,000	39.1	1.50	10.2	
997,900	748,400	1,123,000	57,500	37.7	1.54	9.92	B18
977,700	733,300	1,100,000	49,200	37.1	1.56	9.82	
946,100	709,600	1,064,000	36,700	36.2	1.59	9.66	
1,132,000	849,300	1,274,000	77,900	61.3	1.71	16.3	B15b
945,600	709,200	1,064,000	90,800	41.9	1.49	11.6	B15a
867,600	650,700	976,100	54,800	38.3	1.55	10.9	
689,500	517,100	775,700	60,000	25.2	1.36	7.40	
649,400	487,100	730,600	39,900	24.0	1.41	7.15	B15
629,500	472,100	708,200	30,100	23.4	1.44	7.03	
478,600	359,000	538,400	32,200	21.3	1.42	6.77	B12a
406,200	304,700	457,000	35,800	16.0	1.30	5.14	B12
384,400	288,300	432,500	22,200	15.3	1.35	4.98	
287,100	215,300	323,000	39,000	12.1	1.21	4.05	B10
262,200	196,700	295,000	21,000	11.2	1.27	3.83	
218,300	163,700	245,600	32,900	8.8	1.12	3.17	B9
201,800	151,400	227,000	20,100	8.2	1.17	3.02	
161,600	121,200	181,800	26,000	6.7	1.08	2.51	B8
153,000	114,800	172,100	18,900	6.4	1.11	2.43	

C, C', and C'' = coefficients given in the table.

$W = \frac{C}{L}$, or $\frac{C'}{L}$, or $\frac{C''}{L}$; $M = \frac{C}{8}$, or $\frac{C'}{8}$, or $\frac{C''}{8}$

C, or C', or $C'' = WL = 8M = \frac{2}{3}fS$

TABLE 188.—BETHLEHEM GIRDER

Section number	Nominal depth of beam, inches	Weight, lbs. per foot	Area of section, square inches	Thickness of web, inches	Width of flange, inches	Axis XX* Moment of inertia *I*	Axis XX* Radius of gyration *r*	Axis XX* Section modulus *S*
	30 1/8	200.0	58.52	.76	15.04	9,148.8	12.50	607.5
G30	30	190.0	55.52	.72	15.00	8,651.1	12.48	576.7
	29 7/8	181.0	52.82	.69	14.97	8,181.0	12.45	547.6
G28	28 1/8	175.0	51.02	.70	14.29	6,988.7	11.70	497.1
	28	165.0	48.19	.66	14.25	6,577.9	11.68	469.9
	26 1/8	160.0	46.85	.67	13.79	5,576.6	10.91	427.0
G26	26	151.0	44.16	.63	13.75	5,237.1	10.89	402.9
	25 7/8	144.0	41.99	.61	13.73	4,930.6	10.84	381.0
	24 1/8	149.0	43.57	.65	13.29	4,451.1	10.11	369.1
G24a	24	141.0	41.02	.61	13.25	4,174.2	10.09	347.9
	23 7/8	133.0	38.71	.58	13.22	3,912.4	10.05	327.7
	24 1/8	129.0	37.74	.58	12.29	3,844.8	10.09	318.8
G24	24	121.0	35.30	.54	12.25	3,585.3	10.08	298.8
	23 7/8	114.0	33.12	.51	12.22	3,340.6	10.04	279.8
	20 1/8	149.0	43.44	.69	12.78	3,106.6	8.46	308.8
G20a	20	142.0	41.31	.66	12.75	2,932.3	8.43	293.2
	19 7/8	135.0	39.18	.63	12.72	2,760.6	8.39	277.7
	20 1/8	120.0	34.95	.59	12.03	2,505.5	8.47	249.1
G20	20	113.0	32.90	.56	12.00	2,340.2	8.43	234.0
	19 7/8	107.0	31.06	.54	11.98	2,184.0	8.39	219.7
	18 1/8	100.0	29.25	.52	11.54	1,725.7	7.68	190.5
G18	18	93.0	27.14	.48	11.50	1,593.4	7.66	177.0
	17 7/8	87.5	25.40	.46	11.48	1,472.8	7.61	164.7
	15 1/8	147.0	42.73	.83	11.78	1,666.2	6.24	220.4
G15b	15	141.0	40.86	.80	11.75	1,577.7	6.21	210.4
	14 7/8	135.0	39.01	.77	11.72	1,490.7	6.18	200.4
	15 1/8	111.0	32.40	.64	11.29	1,306.3	6.35	172.8
G15a	15	105.0	30.45	.60	11.25	1,218.2	6.32	162.4
	14 7/8	99.0	28.65	.57	11.22	1,134.7	6.29	152.5
	15 1/8	80.5	23.44	.48	10.79	968.5	6.43	128.1
G15	15	74.0	21.55	.44	10.75	883.8	6.40	117.8
	14 7/8	69.0	19.96	.42	10.73	806.4	6.36	108.4
	12 1/8	76.5	22.29	.51	10.29	589.0	5.14	97.2
G12a	12	70.5	20.57	.47	10.25	538.4	5.12	89.7
	11 7/8	66.0	19.11	.45	10.23	491.7	5.07	82.8
	12 1/8	61.0	17.77	.41	10.03	479.9	5.20	79.2
G12	12	55.5	16.21	.38	10.00	431.8	5.16	72.0
	11 29/32	51.5	15.07	.36	9.98	396.9	5.13	66.6
	10 1/8	50.0	14.51	.36	9.04	275.5	4.36	54.4
G10	10	44.5	13.03	.32	9.00	244.7	4.33	48.9
	9 29/32	41.5	12.12	.31	8.99	223.8	4.30	45.2
	9 1/8	43.5	12.62	.35	8.54	193.8	3.92	42.5
G9	9	38.5	11.23	.31	8.50	170.3	3.89	37.9
	8 15/16	36.0	10.55	.29	8.48	158.9	3.88	35.5
	8 1/8	37.0	10.77	.33	8.03	131.1	3.49	32.3
G8	8	33.0	9.57	.30	8.00	114.2	3.45	28.6
	7 15/16	31.0	9.01	.29	7.99	106.2	3.43	26.7

W = Safe load in pounds, uniformly distributed, including weight of beam.
L = Span, in feet.
M = Moment of forces, in foot pounds.
f = Allowable fiber stress, in lbs. per square inch.
S = Section modulus about axis XX.

* Axis XX parallel to flange. Axis YY parallel to web.

Beam (1926 Standard)

Coefficients of strength: For fiber stress of 16,000 lbs. per sq. in. Usual building code requirement C	For fiber stress of 12,000 lbs. per sq. in. For moving loads C'	For fiber stress of 18,000 lbs. per sq. in. For quiescent loads C''	Maximum safe shear on web, in pounds	Axis YY*: Moment of inertia I'	Radius of gyration r'	Section modulus S'	Section number
6,480,000	4,860,000	7,290,000	193,200	628.5	3.28	83.6	
6,152,000	4,614,000	6,921,000	176,400	589.4	3.26	78.6	G30
5,841,000	4,381,000	6,571,000	163,799	552.0	3.23	73.7	
5,302,000	3,976,000	5,965,000	164,800	496.2	3.12	69.4	G28
5,012,000	3,759,000	5,638,000	149,100	462.8	3.10	65.0	
4,555,000	3,416,000	5,124,000	149,500	432.8	3.04	62.8	
4,297,000	3,223,000	4,834,000	134,900	402.7	3.02	58.6	G26
4,064,000	3,048,000	4,572,000	127,300	375.0	2.99	54.6	
3,937,000	2,953,000	4,429,000	138,200	383.3	2.97	57.7	
3,710,000	2,783,000	4,174,000	124,600	356.4	2.95	53.8	G24a
3,495,000	2,621,000	3,932,000	114,400	330.7	2.92	50.0	
3,401,000	2,550,000	3,826,000	114,800	278.2	2.72	45.3	
3,187,000	2,390,000	3,585,000	101,400	256.9	2.70	41.9	G24
2,984,000	2,238,000	3,357,000	91,400	236.7	2.67	38.7	
3,294,000	2,470,000	3,706,000	138,100	384.5	2.97	60.2	
3,128,000	2,346,000	3,519,000	129,200	360.9	2.96	56.6	G20a
2,962,000	2,222,000	3,333,000	120,500	337.6	2.94	53.1	
2,657,000	1,992,000	2,989,000	109,800	260.1	2.73	43.2	
2,496,000	1,872,000	2,808,000	101,000	240.8	2.71	40.1	G20
2,344,000	1,758,000	2,637,000	95,100	222.3	2.68	37.1	
2,032,000	1,524,000	2,286,000	86,300	202.6	2.63	35.1	
1,888,000	1,416,000	2,125,000	76,000	185.1	2.61	32.2	G18
1,757,000	1,318,000	1,977,000	70,700	168.9	2.58	29.4	
2,351,000	1,763,000	2,645,000	125,500	347.3	2.85	59.0	
2.244,000	1,683,000	2,524,000	120,000	328.3	2.83	55.9	G15b
2,137,000	1,603,000	2,404,000	114,600	309.5	2.82	52.8	
1.843,000	1,382,000	2,074,000	96,800	231.2	2.67	41.0	
1,733,000	1,299,000	1,949,000	90,000	214.3	2.65	38.1	G15a
1,627,000	1,220,000	1,830,000	84,800	198.4	2.63	35.4	
1,367,000	1,025,000	1,537,000	69,700	143.0	2.47	26.5	
1,257,000	942,800	1,414,000	61,100	128.9	2.45	24.0	G15
1,156,000	867,100	1,301,000	56,600	115.8	2.41	21.6	
1,037,000	777,600	1,166,000	61,800	132.1	2.43	25.7	
957,100	717,800	1,077,000	56,400	119.7	2.41	23.4	G12a
883,000	662,300	993,400	53,500	108.3	2.38	21.2	
844,700	633,500	950,300	49,100	95.8	2.32	19.1	
767,700	575,800	863,600	43,800	84.9	2.29	17.0	G12
710,800	533,100	799,700	40,300	76.9	2.26	15.4	
580,800	435,600	653,300	36,400	66.4	2.14	14.7	
522,100	391,500	587,300	31,100	58.2	2.11	12.9	G10
481,900	361,400	542,100	29,500	52.6	2.08	11.7	
453,400	340,000	510,000	31,900	51.3	2.02	12.0	
403,800	302,800	454,300	27,900	44.4	1.99	10.4	G9
379,200	284,400	426,600	25,300	41.0	1.97	9.67	
344,500	258,400	387,600	26,800	38.7	1.90	9.65	
304,500	228,400	342,600	24,000	33.2	1.86	8.29	G8
285,200	213,900	320,900	23,000	30.5	1.84	7.63	

C, C', and C'' = coefficients given in the table.

$W = \frac{C}{L}$, or $\frac{C'}{L}$, or $\frac{C''}{L}$; $M = \frac{C}{8}$, or $\frac{C'}{8}$, or $\frac{C''}{8}$

C, or C', or $C'' = WL = 8M = \frac{4}{3}fS$

TABLE 189A.—WEIGHTS OF FLAT ROLLED STEEL BARS, POUND PER LINEAR FOOT

One cubic foot of steel weighs 489.6 lb. For thicknesses from 3/16 to 2″ and widths from 1 to 12¾″

Thickness in inches	1″	1¼″	1½″	1¾″	2″	2¼″	2½″	2¾″	12″
3/16	0.638	0.797	0.956	1.12	1.28	1.43	1.59	1.75	7.65
¼	0.850	1.06	1.28	1.49	1.70	1.91	2.13	2.34	10.20
5/16	1.06	1.33	1.59	1.86	2.13	2.39	2.66	2.92	12.75
⅜	1.28	1.59	1.91	2.23	2.55	2.87	3.19	3.51	15.30
7/16	1.49	1.86	2.23	2.60	2.98	3.35	3.72	4.09	17.85
½	1.70	2.13	2.55	2.98	3.40	3.83	4.25	4.68	20.40
9/16	1.91	2.39	2.87	3.35	3.83	4.30	4.78	5.26	22.95
⅝	2.13	2.66	3.19	3.72	4.25	4.78	5.31	5.84	25.50
11/16	2.34	2.92	3.51	4.09	4.68	5.26	5.84	6.43	28.05
¾	2.55	3.19	3.83	4.46	5.10	5.74	6.38	7.01	30.60
13/16	2.76	3.45	4.14	4.83	5.53	6.22	6.91	7.60	33.15
⅞	2.98	3.72	4.46	5.21	5.95	6.69	7.44	8.18	35.70
15/16	3.19	3.98	4.78	5.58	6.38	7.17	7.97	8.77	38.25
1	3.40	4.25	5.10	5.95	6.80	7.65	8.50	9.35	40.80
1 1/16	3.61	4.52	5.42	6.32	7.23	8.13	9.03	9.93	43.35
1⅛	3.83	4.78	5.74	6.69	7.65	8.61	9.56	10.52	45.90
1 3/16	4.04	5.05	6.06	7.07	8.08	9.08	10.09	11.10	48.45
1¼	4.25	5.31	6.38	7.44	8.50	9.56	10.63	11.69	51.00
1 5/16	4.46	5.58	6.69	7.81	8.93	10.04	11.16	12.27	53.55
1⅜	4.68	5.84	7.01	8.18	9.35	10.52	11.69	12.86	56.10
1 7/16	4.89	6.11	7.33	8.55	9.78	11.00	12.22	13.44	58.65
1½	5.10	6.38	7.65	8.93	10.20	11.48	12.75	14.03	61.20
1 9/16	5.31	6.64	7.97	9.30	10.63	11.95	13.28	14.61	63.75
1⅝	5.53	6.91	8.29	9.67	11.05	12.43	13.81	15.19	66.30
1 11/16	5.74	7.17	8.61	10.04	11.48	12.91	14.34	15.78	68.85
1¾	5.95	7.44	8.93	10.41	11.90	13.39	14.88	16.36	71.40
1 13/16	6.16	7.70	9.24	10.78	12.33	13.87	15.41	16.95	73.95
1⅞	6.38	7.97	9.56	11.16	12.75	14.34	15.94	17.53	76.50
1 15/16	6.59	8.23	9.88	11.53	13.18	14.82	16.47	18.12	79.05
2	6.80	8.50	10.20	11.90	13.60	15.30	17.00	18.70	81.60

TABLE 189A.—*Continued*

Thickness in inches	3″	3¼″	3½″	3¾″	4″	4¼″	4½″	4¾″	12″
3/16	1.91	2.07	2.23	2.39	2.55	2.71	2.87	3.03	7.65
1/4	2.55	2.76	2.98	3.19	3.40	3.61	3.83	4.04	10.20
5/16	3.19	3.45	3.72	3.98	4.25	4.52	4.78	5.05	12.75
3/8	3.83	4.14	4.46	4.78	5.10	5.42	5.74	6.06	15.30
7/16	4.46	4.83	5.21	5.58	5.95	6.32	6.69	7.07	17.85
1/2	5.10	5.53	5.95	6.38	6.80	7.22	7.65	8.08	20.40
9/16	5.74	6.22	6.69	7.17	7.65	8.13	8.61	9.08	22.95
5/8	6.38	6.91	7.44	7.97	8.50	9.03	9.56	10.09	25.50
11/16	7.01	7.60	8.18	8.77	9.35	9.93	10.52	11.10	28.05
3/4	7.65	8.29	8.93	9.56	10.20	10.84	11.48	12.11	30.60
13/16	8.29	8.98	9.67	10.36	11.05	11.74	12.43	13.12	33.15
7/8	8.93	9.67	10.41	11.16	11.90	12.64	13.39	14.13	35.70
15/16	9.56	10.36	11.16	11.95	12.75	13.55	14.34	15.14	38.25
1	10.20	11.05	11.90	12.75	13.60	14.45	15.30	16.15	40.80
1 1/16	10.84	11.74	12.64	13.55	14.45	15.35	16.26	17.16	43.35
1 1/8	11.48	12.43	13.39	14.34	15.30	16.26	17.21	18.17	45.90
1 3/16	12.11	13.12	14.13	15.14	16.15	17.16	18.17	19.18	48.45
1 1/4	12.75	13.81	14.88	15.94	17.00	18.06	19.13	20.19	51.00
1 5/16	13.39	14.50	15.62	16.73	17.85	18.97	20.08	21.20	53.55
1 3/8	14.03	15.19	16.36	17.53	18.70	19.87	21.04	22.21	56.10
1 7/16	14.66	15.88	17.11	18.33	19.55	20.77	21.99	23.22	58.65
1 1/2	15.30	16.58	17.85	19.13	20.40	21.68	22.95	24.23	61.20
1 9/16	15.92	17.27	18.59	19.92	21.25	22.58	23.91	25.23	63.75
1 5/8	16.58	17.96	19.34	20.72	22.10	23.48	24.86	26.24	66.30
1 11/16	17.21	18.65	20.08	21.52	22.95	24.38	25.82	27.25	68.85
1 3/4	17.85	19.34	20.83	22.31	23.80	25.29	26.78	28.26	71.40
1 13/16	18.49	20.03	21.57	23.11	24.65	26.19	27.73	29.27	73.95
1 7/8	19.13	20.72	22.31	23.91	25.50	27.09	28.69	30.28	76.50
1 15/16	19.76	21.41	23.06	24.70	26.35	28.00	29.64	31.29	79.05
2	20.40	22.10	23.80	25.50	27.20	28.90	30.60	32.30	81.60

TABLE 189B.—WEIGHTS OF 100 MACHINE BOLTS WITH SQUARE HEADS AND NUTS

Wrought iron, manufacturers' standard sizes. Basis, Hoopes & Townsend's list

Length under head to point, inches	Diameter of bolt, in inches							
	7/8	1	1 1/8	1 1/4	1 3/8	1 1/2	1 3/4	2
2	98	145						
2 1/2	106	153						
3	114	163	240	309	350	480		
3 1/2	122	174	253	325	370	500		
4	130	185	267	342	390	520	800	
4 1/2	138	196	281	359	410	545	833	
5	147	207	295	376	430	570	866	1370
5 1/2	155	218	309	394	450	595	900	1414
6	163	229	323	412	470	620	934	1458
6 1/2	172	240	337	430	490	645	968	1502
7	180	251	351	448	510	670	1002	1546
7 1/2	187	262	365	466	530	695	1036	1590
8	195	273	379	484	550	725	1070	1634
9	212	295	407	518	590	775	1138	1722
10	229	317	435	552	630	825	1206	1810
11	246	339	463	586	670	875	1274	1898
12	263	361	491	620	710	925	1342	1986
13	280	383	519	655	751	975	1410	2074
14	297	405	547	690	793	1025	1478	2162
15	314	427	575	725	835	1075	1548	2250
16	331	449	603	760	877	1125	1616	2338
17	348	471	631	795	919	1175	1684	2426
18	365	493	659	830	961	1225	1752	2514
19	382	515	687	865	1003	1275	1820	2602
20	399	537	715	900	1045	1325	1888	2690
21	416	559	743	935	1087	1375	1956	2778
22	437	581	771	970	1129	1425	2024	2866
23	454	603	799	1005	1171	1475	2092	2954
24	470	625	827	1040	1213	1525	2160	3042
25	487	647	855	1075	1255	1575	2228	3130

Bolts from 1 1/8 to 2", inclusive, are fitted with nuts made to U. S. standard

Weights of 100 Round-headed Rivets or Round-headed Bolts without Nuts

Wrought iron, basis—1 cu. ft. iron = 480 lb.

Length under head to point, inches	Diameter of rivet, in inches						
	3/8	1/2	5/8	3/4	7/8	1	1 1/8
1	4.7	9.3	16.0	25.2	37.2	52.6	71.3
1 1/4	5.5	10.7	18.1	28.3	41.3	58.0	78.2
1 1/2	6.2	12.1	20.2	31.3	45.5	63.5	85.1
1 3/4	7.0	13.4	22.4	34.4	49.7	68.9	92.0
2	7.8	14.8	24.5	37.5	53.9	74.4	98.0
2 1/4	8.5	16.2	26.6	40.5	58.0	79.8	105.8
2 1/2	9.3	17.5	28.8	43.6	62.2	85.3	112.7
2 3/4	10.1	18.9	30.9	46.7	66.4	90.7	119.6
3	10.8	20.3	33.0	49.8	70.6	96.2	126.5
3 1/4	11.6	21.6	35.1	52.8	74.7	101.6	133.4
3 1/2	12.4	23.0	37.3	55.9	78.9	107.1	140.3
3 3/4	13.1	24.3	39.4	59.0	83.1	112.6	147.2
4	13.9	25.7	41.5	62.0	87.3	118.0	154.1
4 1/4	14.7	27.1	43.7	65.1	91.4	123.5	161.0
4 1/2	15.4	28.4	45.8	68.2	95.6	128.9	167.9
4 3/4	16.2	29.8	47.9	71.2	99.8	134.4	174.8
5	17.0	31.2	50.1	74.3	104.0	139.8	181.7
5 1/4	17.7	32.5	52.2	77.4	108.2	145.3	188.6
5 1/2	18.5	33.9	54.3	80.4	112.3	150.7	195.6
5 3/4	19.3	35.3	56.4	83.5	116.5	156.2	202.5
6	20.0	36.6	58.6	86.6	120.7	161.6	209.4
6 1/4	20.8	38.0	60.7	89.6	124.8	167.1	216.3
6 1/2	21.6	39.3	62.8	92.7	129.0	172.5	223.2
6 3/4	22.3	40.7	65.0	95.8	133.2	178.0	230.1
7	23.1	42.1	67.1	98.8	137.4	183.5	237.0
7 1/4	23.9	43.4	69.2	101.9	141.6	188.9	243.9
7 1/2	24.6	44.8	71.4	105.0	145.7	194.4	250.8
7 3/4	25.4	46.2	73.5	108.0	149.9	199.8	257.7
8	26.2	47.5	75.6	111.1	154.1	205.3	264.6
8 1/2	27.7	50.2	79.9	117.2	162.4	216.2	278.4
9	29.2	53.0	84.1	123.4	170.8	227.1	292.2
9 1/2	30.8	55.7	88.4	129.5	179.1	238.0	306.0
10	32.3	58.4	92.7	135.6	187.5	248.8	319.8
10 1/2	33.8	61.2	96.9	141.8	195.8	259.8	333.6
11	35.4	63.9	101.2	147.9	204.2	270.7	347.4
11 1/2	36.9	66.6	105.4	154.1	212.5	281.6	361.2
12	38.4	69.3	109.7	160.2	220.9	292.5	375.0
1″ in length of 100 rivets	3.07	5.45	8.52	12.27	16.70	21.82	27.61
Weight of 100 rivet heads	1.78	4.82	9.95	16.12	24.29	34.77	47.67

Table 190.—Weight of Corrugated Metal Galvanized Sheets

Weight in pounds per 100 sq. ft.

Corrugations, inches		Thickness, U. S. Standard gage														
Width	Depth	10	12	14	16	18	20	21	22	23	24	25	26	27	28	29
5	7/8	...	486	352	285	231	178	164	151	137	124	111		97	90	84	77
3	9/16	...	488	353	286	232	178	165	151	138	125	111		98	91	84	77
2 1/2	1/2	631	494	358	290	235	181	167	153	140	126	113		99	92	85	78
2 1/2	1/2	623	488	353	286	232	178	165	151	138	125	111		98	91	84	77
2	7/16	...	...	...	286	232	178	165	151	138	125	111		98	91	84	77
1 1/4	3/8	...	...	...	...	...	186	172	158	144	130	116	102	95	88	81
5/8	3/16	...	...	...	...	...	...	...	...	...	130	116	102	95	88	81

Note.—Painted sheets weigh about 16 lb. less per 100 sq. ft. than the galvanized sheets.

Table 191.—Condensed Table of Strength of Reinforced-concrete Slabs (Free End Supports)

Safe uniformly distributed superimposed load per square foot of slab for the span noted, exclusive of weight of slab

Factor of safety 5 which is *very conservative.*

(Note.—For factor of safety of 4 add one-fourth to the tabular loads.)

Concrete 1:2:4 mix.

Allowable unit stress in concrete . . 500 lb. per square inch.
Allowable unit stress in steel . . 14,000 lb. per square inch.

Note.—The safe concentrated load is one-half of the total uniformly distributed load over the effective width of slab resisting a concentrated load (see page 1042).

TABLE 191.—*Continued*

Span in Feet	Depth of Slab in Inches									
	6″	8″	10″	12″	14″	16″	18″	20″	22″	24″
2	3,810									
4	895	1,760	2,810	4,300	5,840					
6	355	725	1,180	1,830	2,500	3,390	4,420			
8	163	365	600	960	1,320	1,810	2,380	2,860	3,570	
10	80	197	340	550	780	1,090	1,440	1,730	2,180	2,670
12	....	100	200	340	490	690	930	1,120	1,420	1,750
14	....	....	110	210	310	450	620	760	970	1,210
16	....	....	....	120	190	300	420	520	680	750
18	....	....	....	....	....	190	280	350	470	610
20	....	....	....	....	....	....	200	230	330	430
22	....	....	....	....	....	....	....	180	220	310
24	....	....	....	....	....	....	....	....	150	210
Resisting moment of slab in ft. lb. per ft. width of slab	1,925	3,770	5,890	8,900	12,030	16,170	20,960	24,940	30,800	37,260
Net area of rods (sq. in.)	0.25	0.25	0.39	0.39	0.56	0.56	0.77	0.77	1.00	1.00
Spacing of rods (in.)	6″	5″	6″	5″	6″	5″	6″	5″	6″	5″
Depth below steel	1.00″	1.00″	1.25″	1.50″	1.50″	1.50″	1.50″	2.00″	2.00″	2.00″
Weight of slab per sq. ft.	77	103	128	154	180	206	232	257	283	310

TABLE 192.—CONDENSED TABLE OF STRENGTH OF REINFORCED-CONCRETE BEAMS (Free End Supports)

Safe uniformly distributed superimposed load per foot length of beam per inch width of beam, exclusive of weight of beam.

To get the total superimposed load per foot length of the beam multiply the tabular load by the width of beam in inches.

Factor of safety 5 (conservative practice). (1:2:4 mix)

Span in Feet	Depth of Beam in Inches						
	12″	18″	24″	30″	36″	42″	48″
6	152	370					
8	80	200	362				
10	46	120	222	370	540	760	
12	28	78	146	247	360	510	690
14	17	52	100	173	255	360	490
16	......	35	70	125	190	270	360
18	......	......	50	92	140	200	280
20	......	......	......	70	110	160	210
25	......	......	......	......	55	80	120
30	......	......	......	......	......	45	70
35	......	......	......	......	......	......	35
Resisting moment of beam in ft. lb. per inch width	740	1,740	3,100	5,030	7,200	10,000	13,300
Area of steel (sq. in.) per inch width	0.066	0.101	0.134	0.171	0.210	0.240	0.278
Distance from steel to bottom of beam	1.5″	1.5″	2.0″	2.0″	2.5″	2.5″	2.5″
Weight of beam 1″ wide, 1′ long	12.8lb.	19.2lb.	25.7lb.	32.1lb.	38.5lb.	44.9lb.	51.4lb.

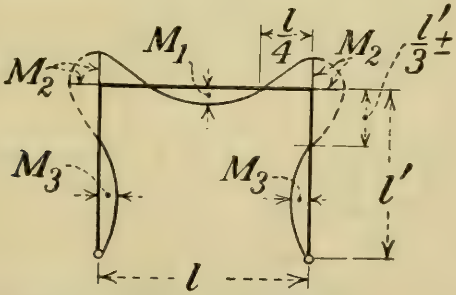
Table 193.—Recommended Thickness of Concrete Slab When Used in Highway Bridges under Different Depths of Earth or Macadam Fill (Conservative Practice)

Span of Slab in Feet	Depth of Fill Over Slab in Feet						
	1′	2′	4′	6′	8′	10′	12′
2	6″	6″	6″	6″	6″	6″	6″
4	7″	7″	7″	7″	7″	7″	7″
6	9″	9″	9″	10″	10″	10″	11″
8	10″	10″	10″	11″	12″	13″	13″
10	12″	12″	13″	14″	15″	16″	17″
12	14″	14″	15″	16″	17″	18″	20″
14	16″	16″	17″	18″	19″	20″	22″
16	18″	18″	19″	20″	22″	24″	
18	20″	20″	22″	23″	24″		
20	22″	22″	23″	24″			

Note.—Side walls must be designed for beam action due to horizontal earth pressure—deep fills (see Fig. 67, p. 224, Chap. IV Part I).

Design of Structures under Deep Fills.—Design culverts and slab bridges under deep fills on the principle of rigid frames pin connected at the bottom of side walls.

Stresses are indeterminate and the usual formulæ are very complicated. The following simple formulæ have been found to be satisfactory and are conservative.



Approximate moment diagram.

$M_1 = 0.09\ Wl$, vertical loads.

$M_2 = 0.06\ Wl$, vertical loads $+\ 0.06\ W'l'$ horizontal pressure on sidewalls.

$M_3 = 0.12\ W'l'$, horizontal pressure.

Table 194.—Condensed Table of Strength of Wooden Beams

Based on a very complete table published in the Cambria Steel Handbook to which the reader is referred if he is using much data of this kind.

This tabulation based on factor of safety of 6.

Allowable fiber stress 1200 lb. per square inch.

The loads given are the safe total uniformly distributed loads per inch width of beam for the span noted including the weight of the beam.

This table applies directly to white oak and long-leaf yellow pine.

For hemlock use one-half of the load given.

For Douglas fir, Norway pine, cypress, chestnut, and spruce, use two-thirds of the load given.

Note.—The safe concentrated superimposed load is one-half of the total superimposed uniformly distributed load exclusive of the weight of the beam.

For weight of timber see page 1038.

Span in Feet	Depth of Beam in Inches										
	4″	6″	8″	10″	12″	14″	16″	18″	20″	22″	24″
4	535	1200									
6	355	800	1420								
8	270	600	1070	1670	2400						
10	215	480	850	1330	1920	2610					
12	180	400	710	1110	1600	2180	2840	3600			
14	150	340	610	950	1370	1870	2440	3090	3810		
16	135	300	530	830	1200	1630	2130	2700	3330	4030	4800
18	120	270	480	740	1070	1450	1900	2400	2960	3590	4270
20	105	240	430	670	960	1310	1710	2160	2670	3230	3840
22	95	220	390	610	870	1190	1550	1960	2420	2930	3490
24	90	200	360	560	800	1090	1420	1800	2220	2690	3200
26		185	330	510	740	1000	1310	1660	2050	2480	2950
28		170	305	480	690	930	1220	1540	1900	2300	2740
30		160	285	440	640	870	1140	1440	1780	2150	2560

Note.—If a deep beam is used for a shorter span than shown in the table figure the limiting load on the basis of shear along the neutral axis. By the formula

$$W = \frac{4bds}{3},$$

In which W = safe load in pounds uniformly distributed.

d = depth of beam in inches.

b = breadth of beam in inches.

S = allowable shear in the direction of the grain in pounds per square inch.

White pine................ 100 lb. per square inch.

Long-leaf yellow pine....... 150 lb. per square inch.

White oak................ 200 lb. per square inch.

The Deflection formula for a beam 1″ wide under uniform load may be written $f = 270\ (l/d)^3 W/E$. Following table gives values of $270\ (l/d)^3$ for various spans and widths. In this formula, l is expressed in feet, f and d in inches, W in pounds of total load on beam divided by width in inches.

Table 195.—Deflection of Timber Beams

Values of C in the Formula, Deflection = CW/E for Beams 1″ Wide and Uniformly Loaded

Span in feet	Depth in inches										
	4	6	8	10	12	14	16	18	20	22	24
5	530	160	66	34	20	12					
6	910	270	110	58	34	20	14				
7	1,450	430	180	93	54	33	23				
8	2,160	640	270	140	80	50	34				
9	3,080	910	380	200	110	71	48				
10	4,220	1,250	530	270	160	98	66	46	34	25	20
11	5,620	1,660	700	360	210	130	88	61	45	33	26
12	7,310	2,160	910	470	270	170	110	79	59	43	34
13	9,270	2,750	1,160	590	340	220	150	100	75	55	43
14	11,580	3,430	1,450	740	430	270	180	130	93	69	53
15	14,240	4,220	1,780	910	530	330	220	160	120	84	66
16	17,280	5,120	2,160	1,110	640	400	270	190	140	100	80
17	......	6,140	2,590	1,330	770	480	330	230	170	120	96
18	......	7,290	3,070	1,580	910	570	390	270	200	150	110
19	......	8,570	3,610	1,850	1,070	670	450	320	230	170	130
20	......	10,000	4,220	2,160	1,250	780	530	370	270	200	160
21	......	......	4,880	2,500	1,450	910	610	430	320	230	180
22	......	......	5,610	2,880	1,660	1,050	700	490	360	270	210
23	......	......	6,410	3,280	1,900	1,200	800	560	410	300	230
24	......	......	7,290	3,730	2,160	1,350	910	640	470	350	270
25	......	......	.....	4,220	2,440	1,540	1,030	720	530	390	310
26	......	......	.....	4,740	2,740	1,730	1,160	810	590	440	340
27	......	......	.....	5,310	3,070	1,930	1,300	910	660	500	390
28	......	......	.....	5,930	3,420	2,160	1,450	1,020	740	550	430
29	......	......	.....	6,590	3,810	2,390	1,610	1,130	820	620	480
30	......	......	.....	7,290	4,210	2,650	1,780	1,250	910	680	530
31	......	......	.....	.....	.....	.....	1,970	1,380	1,010	750	580
32	......	......	.....	.....	.....	.....	2,160	1,520	1,110	830	640
33	......	......	.....	.....	.....	.....	2,370	1,660	1,220	900	710
34	......	......	.....	.....	.....	.....	2,590	1,820	1,330	990	770
35	......	......	.....	.....	.....	.....	2,830	1,980	1,450	1,080	840
36	......	......	.....	.....	.....	.....	3,080	2,160	1,580	1,170	910

Since E varies considerably for woods of the same species, and for different degrees of seasoning and for variations in moisture content, the constants for intermediate depth may be selected by inspection. For a concentrated load at the middle of a beam multiply the value of C by 1.6.

Note.—American Civil Engineers' Handbook, John Wiley & Sons Co.

TABLE 196.—CONDENSED TABLE OF STRENGTH OF TIMBER UNDER LONG COLUMN ACTION

Based on the Formula of the U. S. Department of Agriculture, Division of Forestry.

$$P = F \times \frac{700 + 15C}{700 + 15C + C^2}$$

P = ultimate strength in pounds per square inch
F = " crushing strength of timber
$C = \frac{l}{d}$ in which l = length of column in inches
d = least diameter in inches

Safe load per square inch on the basis of a factor of safety of 8 is given below. A factor of safety of 6 is often used in good practice.

$\frac{l}{d}$	Safe Load in Pounds per Square Inch			
	White Oak and Long Leaf Yellow Pine	Douglas Fir and Short Leaf Yellow Pine	Red Pine, Spruce Hemlock, Cypress, Chestnut	White Pine and Cedar
5	600	550	480	420
10	560	500	450	390
15	510	450	400	350
20	450	400	360	310
25	400	360	320	280
30	350	320	280	250

NOTE.—$\frac{l}{d}$ over 30 is not advised.

TABLE 197.—STANDARD THICKNESS AND WEIGHTS OF CAST-IRON PIPE ADOPTED MAY 12, 1908, BY AMERICAN WATER WORKS ASSOCIATION

Nominal Inside Diameter Inches	LIGHT 100 Foot Head			MEDIUM 200 Foot Head			HEAVY 300 Foot Head			EXTRA HEAVY 400 Foot Head		
	43 Pounds Pressure			86 Pounds Pressure			130 Pounds Pressure			173 Pounds Pressure		
	Thickness	Weight per Foot	Weight per Length	Thickness	Weight per Foot	Weight per Length	Thickness	Weight per Foot	Weight per Length	Thickness	Weight per Foot	Weight per Length
3	.39	14.5	175	.42	16.2	194	.45	17.1	205	.48	18.0	216
4	.42	20.0	240	.45	21.7	260	.48	23.3	280	.52	25.0	300
6	.44	30.8	370	.48	33.3	400	.51	35.8	430	.55	38.3	460
8	.46	42.9	515	.51	47.5	570	.56	52.1	625	.60	55.8	670
10	.50	57.1	685	.57	63.8	765	.62	70.8	850	.68	76.7	920
12	.54	72.5	870	.62	82.1	985	.68	91.7	1,100	.75	100.0	1,200
14	.57	89.6	1,075	.66	102.5	1,230	.74	116.7	1,400	.82	129.2	1,550
16	.60	108.3	1,300	.70	125.0	1,500	.80	143.8	1,725	.89	158.3	1,900
18	.64	129.2	1,550	.75	150.0	1,800	.87	175.0	2,100	.96	191.7	2,300
20	.67	150.0	1,800	.80	175.0	2,100	.92	208.3	2,500	1.03	229.2	2,750
24	.76	204.2	2,450	.89	233.3	2,800	1.04	279.2	3,350	1.16	306.7	3,680
30	.88	291.7	3,500	1.03	333.3	4,000	1.20	400.0	4,800	1.37	450.0	5,400
36	.99	391.7	4,700	1.15	454.2	5,450	1.36	545.8	6,550	1.58	625.0	7,500
42	1.10	512.5	6,150	1.28	591.7	7,100	1.54	716.7	8,600	1.78	825.0	9,900
48	1.26	666.7	8,000	1.42	750.0	9,000	1.71	908.3	10,900	1.96	1,050.0	12,600

TABLE 198.—LOCK JOINT CAST-IRON CULVERT PIPE

Inside diameter, inches	Thickness of pipe, inches	Face of hub, inches	Weight per foot, pounds	Length of units, feet
12	7/16	9/16	60	4
16	1/2	5/8	80	4
18	1/2	5/8	90	4
24	9/16	1 1/16	115	3
30	1 1/16	3/4	185	3 and 5
36	3/4	1 3/16	250	3 and 5
42	1 3/16	1 5/16	350	4
48	7/8	1	450	5

TABLE 199.—AREAS AND WEIGHTS "ARMCO" CORRUGATEI CULVERTS

(These weights are founded upon careful records made with respec to several thousand feet of each diameter, and very closely approximate the actual weights.)

Diameter in inches	Area in square feet	Weight per foot No. 16 gage	Weight per foot No. 14 gage	Weight per foot No. 12 gage	Weight per foot No. 10 gage
8	0.349	7.4			
10	0.545	9.2	11.3		
12	0.785	10.8	13.2		
15	1.227	13.1	16.0		
18	1.767	15.7	19.3	26.4	
21	2.405	18.4	22.6	30.9	
24	3.142	20.7	25.4	34.9	43.7
30	4.909	....	31.9	43.6	54.4
36	7.069	....	38.1	52.0	64.9
42	9.621	....	44.4	60.6	75.6
48	12.566	....	51.7	70.6	88.1
54	15.904	....	57.9	79.0	98.6
60	19.635	....	....	87.5	109.1
66	23.758	....	....	95.8	119.7
72	28.274	....	....	105.0	130.2
78	33.183	....	....	.....	141.4
84	38.485	....	....	.....	151.8

NOTE.—The only safe way to determine whether culvert pipes are of th correct gage and diameter is to weigh them.

DIAMETER, AREAS, AND RECOMMENDED MINIMUM GAGES OF ARMCO CULVERTS (WITH WEIGHTS PER FOOT), HIGHWAY PRACTICE

Nominal diameter	Area in square feet	Gage	Weight per foot
12	0.785	16	10.8
15	1.227	16	13.1
18	1.767	16	15.7
21	2.405	16	18.4
24	3.142	14	25.4
30	4.909	14	31.9
36	7.069	14	38.1
42	9.621	14	44.4
48	12.566	12	70.6
54	15.904	12	79.0
60	19.635	12	87.5
66	23.758	12	95.8
72	28.274	10	130.2
78	33.183	10	141.4
84	38.485	10	151.8

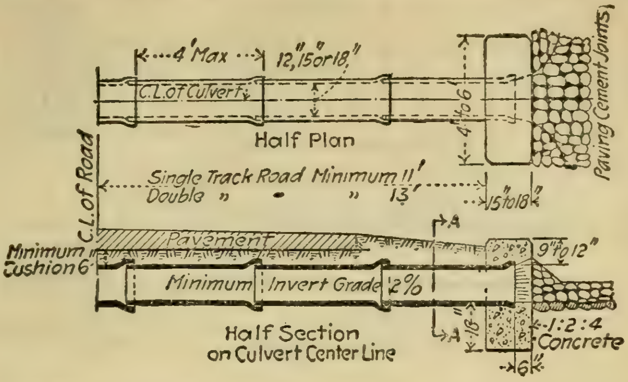
NOTE.—For very severe conditions culverts 48″ and larger in diameter can be supplied in 8-gage Armco ingot iron.

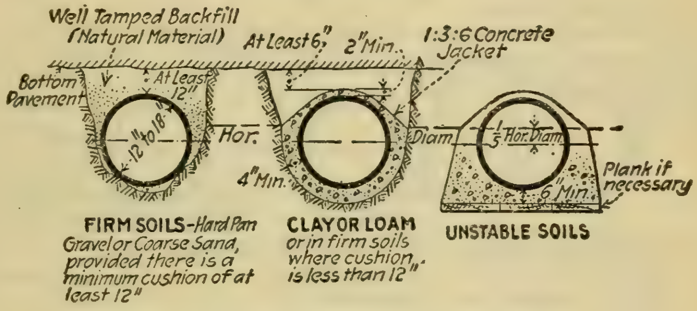
TABLE 199*A*.—RELATIVE CARRYING CAPACITIES OF CORRUGATED CULVERTS UNDER AVERAGE ACTUAL CONDITIONS

Example.—How many 12″ culverts will carry the same amount of water as 36″ culvert? In vertical column for 12″, find, opposite 36″ in horizontal column, 12.07. Ans.

Diameter in inches	12″	15″	18″	21″	24″	30″	36″	42″	48″	54″	60″	66″	72″	78″	84″
12″	1.														
15″	1.20	1.													
18″	2.38	1.17	1.												
21″	3.53	2.34	1.14	1.											
24″	4.67	3.47	2.30	1.14	1.										
30″	7.89	5.69	3.50	2.36	1.23	1.									
36″	12.07	7.87	5.69	3.54	2.41	1.18	1.								
42″	17.23	10.03	7.85	5.69	3.51	2.34	1.15	1.							
48″	23.3	14.16	9.98	6.83	5.69	3.47	2.29	1.14	1.						
54″	30.48	19.28	12.10	8.94	6.81	3.59	2.41	1.25	1.11	1.					
60″	39.5	24.39	16.20	9.95	10.01	5.69	3.51	2.36	1.23	1.11	1.				
66″	49.6	30.48	20.30	14.14	13.11	6.79	4.61	2.46	2.32	2.29	1.10	1.			
72″	59.7	37.57	24.39	17.23	12.10	7.87	5.69	3.54	2.39	1.28	1.18	1.08	1.		
78″	71.8	45.65	29.47	20.31	15.18	9.95	6.77	4.62	3.49	2.36	1.26	1.17	1.08	1.	
84″	84.9	53.72	35.54	24.39	18.25	10.03	7.85	5.69	3.56	2.44	2.34	1.24	1.15	1.07	1.

TABLE 200.—TYPICAL REINFORCED-CONCRETE PIPE CULVERTS





SECTION A-A-Showing Treatment in Different Soils

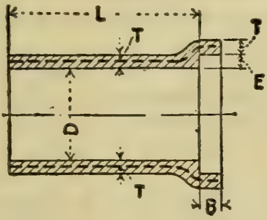
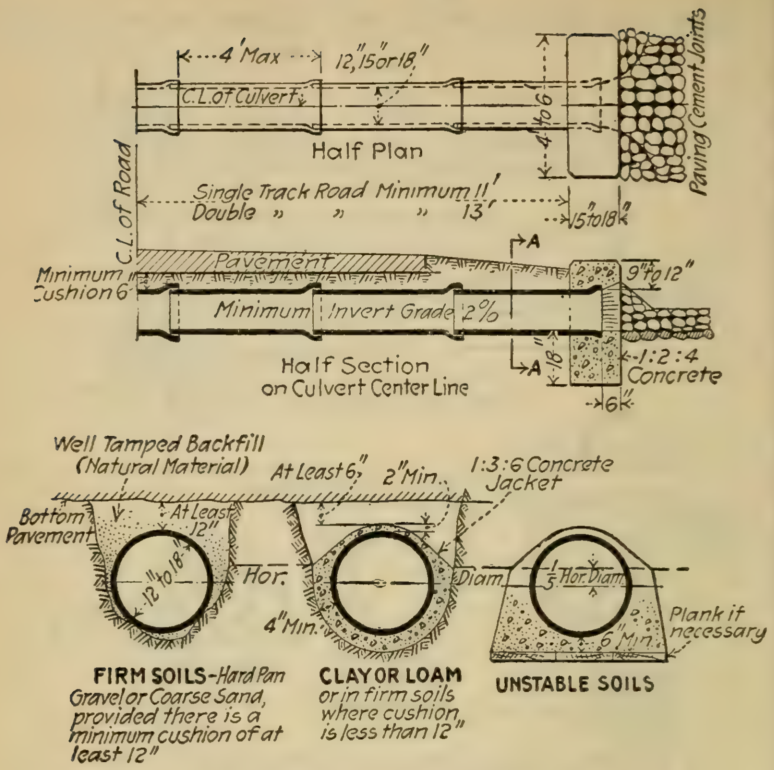


TABLE OF DIMENSIONS AND REINFORCEMENT FOR PIPE

Table of Dimensions

D Inches	L-Max. Feet	T Inches	B-Min. Inches	E Inches
12	4	2	2½	2½
15	4	2	2½	2½
18	4	2½	3	3
24	4	3	3	3½
Effective Area of Circumferal Reinforcement Per Foot Length of Pipe				
12	0.058 Sq. Inches			
15	0.058 " "			
18	0.080 " "			
24	0.126 " "			
Approximate Weight Per Linear Foot of Pipe				
12	90 lbs			
15	110 "			
18	170 "			
24	260 "			



SECTION A-A-Showing Treatment in Different Soils

TABLE 201.—STANDARD VITRIFIED PIPE

APPROXIMATE WEIGHTS, DIMENSIONS, ETC. OF STANDARD SEWERS PIPE

Caliber, in.	Price per foot	Weight, per foot, lbs.	Depth of socket, in.	Annular space, in.	Thickness, in.
12	$1.35	45	2¼	½	1
15	1.80	60	2½	½	1⅛
18	2.50	85	2¾	½	1¼
20	3.00	100	3	½	1⅜
22	4.00	130	3	½	1⅝
24	4.50	140	3¼	½	1⅝

DOUBLE-STRENGTH PIPE

Caliber, in.	Price per foot	Weight per foot, lbs.	Depth of socket, in.	Annular space, in.	Thickness, in.
15	$1.80	75	2½	½	1¼
18	2.50	118	2¾	½	1½
20	3.00	138	3	½	1⅔
22	4.00	157	3	½	1⅚
24	4.50	190	3¼	½	2

General Specifications, Reinforced-concrete Arches, Division 4

Rock or hardpan foundations:

Maximum pressure, hardpan........ 6 tons per square foot
Maximum pressure, soft rock....... 8 tons per square foot
Maximum pressure, hard rock...... 10–20 tons per square foot.

Arches not recommended on pile foundations (12 ton maximum).
Arches not permitted on earth foundations.
Arches not permitted with bottom ties (false arch) for spans over 10′.

Quantity and Cost Diagrams Based on Following Design Assumptions (see page 324)

(Trial Empirical)

Road grade 2.0′ above crown of arch extrados. Crown thickness not less than one-sixtieth of span and varied to agree approximately with Schwada's formulas for highway arches (Ketchum, p. 417).

Approximate spring thickness of arch ring.

3.0 × crown thickness for rise ratio of 0.125.

2.8 × crown thickness for rise ratio of 0.15.

2.5 × crown thickness for rise ratio of 0.25.

Curve of trial arch axis based approximately on Cochran's formulas for filled spandrel arches.

$$Y = \frac{4rL}{1 + 3r}(C^2 + 24C^5r) \text{(Hool and Johnson, p. 671).}$$

Final arch axis to correspond with dead load force polygon.

Minimum longitudinal arch reinforcement 1% at crown.

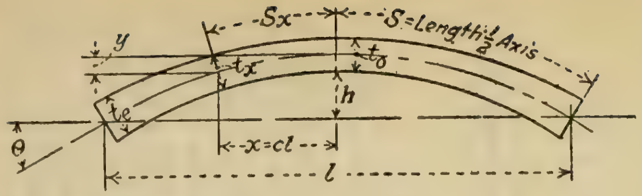
Transverse reinforcement to take full thrust of earth against spandrels and never less than ⅛% of section area.

Arch reinforcement symmetrical.

Spandrel walls cantilever design (see p. 326 and 1019).

Stirrups ¼″ circular spaced twice the depth of the arch ring at crown.

Empirical Test Stability Arch Rings.—A good quick test for the stability of the usual highway arch ring up to 80′ spans, with rise ratios of 0.15 to 0.20 where the arch axis coincides with the dead load force polygon, and where the arch ring has at least the crown thickness shown on page 1087 and the intermediate ring thicknesses are proportioned approximately as per table on page 1087, with symmetrical reinforcement equal to at least 1% of area at crown, is to compute compression in concrete for full dead plus full live load at crown and spring considering load uniformly distributed over section. Uniform compression at crown should not exceed 200 lb. per square inch and at spring 120 lb. per square inch. These limits will automatically take care of distorted live loading, temperature stresses, etc.



r = Rise ratio = $\frac{h}{l}$

u = Ratio of thickness at any point to crown = $\frac{t_x}{t_o}$

$u_S = \frac{t_e}{t_o}$

TABLE 202.—TABLE OF COORDINATES, TRIAL ARCH AXIS FILLED SPANDREL ARCHES

Based on Cochran's Formula

$$y = \frac{4rl}{1 + 3r}(C^2 + 24C^5r)$$

$$\tan\theta = \frac{4r}{1 + 3r}(1 + 7.5\,r)$$

C^2	$24C^5$	x Coordinate in terms of total span l	Partial table y coordinate in terms of span l for different rise ratios										
			r = 0.10	0.12	0.14	0.15	0.16	0.18	0.20	0.25	0.30	0.35	0.40
0.000	0.0000	C = 0.0 crown	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
0.0025	0.000007	C = 0.05											
0.010	0.00024	C = 0.1	0.0031	......	0.00395	0.00414	......	0.00469	0.0050	......	0.00636	......	0.00734
0.022	0.00236	C = 0.15											
0.040	0.00768	C = 0.20	0.01256	......	0.01618	0.017	......	0.01933	0.02077	......	0.02669	......	0.03131
0.062	0.02344	C = 0.25											
0.090	0.05832	C = 0.30	0.02952	......	0.03868	0.0408	......	0.04693	0.05083	......	0.06783	......	0.08239
0.122	0.12605	C = 0.35											
0.160	0.24576	C = 0.40	0.05685	......	0.07600	0.0812	......	0.09538	0.10457	......	0.14748	......	0.18779
0.202	0.44287	C = 0.45											
0.250	0.75000	C = 0.50 spring	0.100	0.120	0.140	0.1500	0.160	0.180	0.200	0.250	0.300	0.350	0.400
Approx. angle θ			28° 20′	33° 50′	38° 45′	41° 10′	43° 20′	47° 35′	51° 20′	58° 40′	64° 00′	67° 54′	71° 00′
Values of $\frac{4r}{1 + 3r}$			0.308	0.352	0.394	0.413	0.432	0.467	0.500	0.571	0.631	0.682	0.727

This rule should not be used for economic design but it affords a good quick check on designs submitted for approval.

Readers are referred to Hool and Johnson's "Concrete Engineers' Handbook"[1] for full details of Cochran's method of arch design, which is probably the best and most practical method at present in use (1926).

TABLE 203.—TABLE OF ARCH THICKNESS
Cochran's Formula

Half axis divided into 10 parts $V = \frac{sx}{s}$	Thickness in terms of crown thickness for different values of *Us**					
	Us 2.0	*Us* 2.25	*Us* 2.50	*Us* 2.75	*Us* 3.0	*Us* 3.25
Crown	1.000	1.000	1.000	1.000	1.000	1.000
0.05*s*	1.005	1.004	1.003	1.002	1.001	1.000
0.15*s*	1.015	1.012	1.009	1.006	1.003	1.000
0.25*s*	1.025	1.020	1.015	1.010	1.005	1.000
0.35*s*	1.035	1.028	1.023	1.021	1.023	1.030
0.45*s*	1.048	1.048	1.057	1.070	1.083	1.101
0.55*s*	1.085	1.105	1.133	1.165	1.193	1.231
0.65*s*	1.168	1.215	1.269	1.328	1.385	1.455
0.75*s*	1.311	1.403	1.508	1.625	1.737	1.865
0.85*s*	1.547	1.700	1.862	2.025	2.185	2.355
0.95*s*	1.837	2.055	2.277	2.495	2.709	2.932
1.00 spring	2.000	2.250	2.500	2.750	3.000	3.250

* $Us = \frac{\text{Arch thickness at spring}}{\text{Arch thickness at crown}}$.

APPROXIMATE TRIAL ARCH THICKNESS AT CROWN (2.0′ FILL OVER ARCH)
Based on Schwada's Rules (Modified)

Span, feet	Crown thickness, in inches, for different rise ratios					
	0.10	0.15	0.20	0.25	0.30	0.40
20	9	8	7	7	7	7
30	10	9	9	9	8	8
40	11	10	10	10	9½	9
50	12	11	11	11	10½	10
60	14	13	12½	12½	12	12
70	16	15	14½	14	14	14
80	19	18	17	16	16	16
Trial type *Us* =	3.25	3.00	2.75	2.50	2.25	2.0

Preliminary Quantity Estimates.—The estimates of quantities are merely arithmetical procedure. The estimating of earth work and overhaul has already been explained in detail (pp. 971 to 1004).

[1] McGraw-Hill Book Company, Inc.

The following tables provide good quick checks on the detail arith metical computations of pavements, and incidental items.

Table 163 (p. 994), conversion lineal feet to miles.
Table 204 (p. 1089), square yards per 100′ and per mile.
Table 205 (p. 1089), cubic yards pavement per 100′.
Table 206 (p. 1090), gallons of bitumen per 100′ road.
Table 207 (p. 1092), materials required for concrete.

In estimating concrete or steel for culverts and bridges it generall pays to prepare a table of quantities for the different standard struc tures of different lengths which are sufficiently close for preliminar estimates. Tables 184 to 207 cover most incidental elements c ordinary drainage structures.

On the completion of the estimate of net quantities the contrac estimate is prepared and tabulated as in following table showin the net quantities, contingent allowance, and gross quantity o which bids are taken.

Engineer's Approx. Estimate of Quantities, Road 502: County of Livingston

Item No.	Item	Quantities		
		Net	Contingent	Gross bid
1	Cleaning and grubbing................	L. S.	....	L. S.
2	Earth excavation, cubic yards..........	52,100	4,900	57,000
3	Rock excavation, cubic yards..........	....	100	100
7	Pipe underdrain, lineal feet...........	500	2,000	2,500
19	Portland cement, barrels..............	19,500	500	20,000
51	Cement-concrete pavement, cubic yards, etc., etc.	9,760	240	10,000

Cost estimates are then prepared (see Chap. XV for computatio of unit costs).

Construction Plans.—The construction plans should giv sufficient information to show the contractor what he is expected t do and to enable the constructing engineer to stake out and to buil the road.

A finished set of plans consists of a map, profile, and cross-sectior showing the alignment in relation to the preliminary survey lin the proposed grade elevations, the shape of the finished road, th widths and depths of road metaling, the crowns to be used, the exis ing structures and the proposed structures, and all the minor point of design. Each department has its own method of giving th information, and it makes little difference how it is shown so lon as it is complete and clear. In general, it may be said that th

cales used are the same as in mapping the preliminary survey and hat the size of sheets or rolls must be convenient to handle in the eld; sheets larger than 24 by 30″ are clumsy.

Miscellaneous Information. *Railroad Crossings.*—The special esign of grade crossings or elimination is discussed in detail in Chap. X, Part I.

ABLE 204.—SQUARE YARDS PER 100 ′AND PER MILE FOR DIFFERENT WIDTH OF SURFACE

Width in Feet	Number of Square Yards		Width in Feet	Number of Square Yards	
	Per 100 Feet	Per Mile		Per 100 Feet	Per Mile
8	88.889	4,693	26	288.889	15,253
10	111.111	5,867	28	311.111	16,427
12	133.333	7,040	30	333.333	17,600
14	155.556	8,213	32	355.556	18,773
15	166.667	8,800	34	377.778	19,947
16	177.778	9,387	36	400.000	21,120
18	200.000	10,560	38	422.222	22,293
20	222.222	11,734	40	444.444	23,466
22	244.444	12,907	42	466.667	24,640
24	266.667	14,080	44	488,889	25,813

TABLE 205.—GIVING THE NUMBER OF CUBIC YARDS OF MACADAM PER 100′ OF ROAD FOR DIFFERENT WIDTHS AND DEPTHS

Width of Macadam	Depth							
	2″	2½″	3″	3½″	4″	5″	6″	7″
10′	6.17	7.71	9.26	10.80	12.34	15.43	18.52	21.61
12′	7.41	9.26	11.11	12.96	14.82	18.52	22.22	25.93
14′	8.64	10.80	12.96	15.12	17.28	21.61	25.92	30.25
15′	9.26	11.58	13.89	16.20	18.52	23.16	27.78	32.41
16′	9.88	12.35	14.81	17.28	19.76	24.70	29.63	34.57
18′	11.11	13.90	16.67	19.44	22.22	27.79	33.34	38.89
20′	12.35	15.44	18.52	21.60	24.70	30.87	37.04	43.21
22′	13.58	16.98	20.37	23.76	27.16	33.96	40.74	47.53

TABLE 206.—GALLONS PER 100′ OF ROAD FOR DIFFERENT WIDTHS AND RATES OF APPLICATION

Width in Feet	Number of Gallons to the Square Yard											
	0.1	0.2	0.25	0.3	0.33⅓	0.4	0.5	0.6	0.66⅔	0.7	0.8	0.9
8	8.89	17.78	22.22	26.67	29.63	35.56	44.44	53.33	59.26	62.22	71.11	80.00
10	11.11	22.22	27.77	33.33	37.04	44.44	55.56	66.67	74.08	77.78	88.89	100.00
12	13.33	26.67	33.33	40.00	44.45	53.33	66.67	80.00	88.89	93.33	106.67	120.00
14	15.56	31.11	38.89	46.67	51.85	62.22	77.78	93.33	103.71	108.89	124.44	140.00
15	16.67	33.33	41.67	50.00	55.56	66.67	83.33	100.00	111.11	116.67	133.33	150.00
16	17.78	35.56	44.44	53.33	59.26	71.11	88.89	106.67	118.52	124.44	142.22	160.00
18	20.00	40.00	50.00	60.00	66.67	80.00	100.00	120.00	133.33	140.00	160.00	180.00
20	22.22	44.44	55.56	66.67	74.07	88.89	111.11	133.33	148.15	155.56	177.78	200.00
22	24.44	48.89	61.11	73.33	81.48	97.78	122.22	146.67	162.97	171.11	195.56	220.00
24	26.67	53.33	66.67	80.00	88.89	106.67	133.33	160.00	177.78	186.67	213.33	240.00
26	28.89	57.78	72.22	86.67	96.29	115.56	144.44	173.33	192.60	202.22	231.11	260.00
28	31.11	62.22	77.78	93.33	103.70	124.44	155.56	186.67	207.41	217.78	248.89	280.00
30	33.33	66.67	83.33	100.00	111.11	133.33	166.67	200.00	222.22	233.33	266.67	300.00
32	35.56	71.11	88.89	106.67	118.51	142.22	177.78	213.33	237.04	248.89	284.44	320.00
34	37.78	75.56	94.44	113.33	125.92	151.11	188.89	226.67	251.86	264.44	302.22	340.00
36	40.00	80.00	100.00	120.00	133.33	160.00	200.00	240.00	266.67	280.00	320.00	360.00
38	41.11	84.44	105.56	126.67	140.73	168.89	211.11	253.33	281.49	295.56	337.78	380.00
40	43.33	88.89	111.11	133.33	148.14	177.78	222.22	266.67	296.30	311.11	355.56	400.00
42	45.56	93.33	116.67	140.00	155.55	186.67	233.33	280.00	311.11	326.67	373.33	420.00
44	48.89	97.77	122.22	146.67	162.96	195.56	244.44	293.33	325.92	342.22	391.11	440.00

TABLE 206.—*Continued*

Width in Feet	Number of Gallons to the Square Yard											
	1.0	1.1	1.2	1.25	1.3	1.33⅓	1.4	1.5	1.6	1.66⅔	1.7	1.8
8	88.89	97.78	106.67	111.11	115.56	118.52	124.44	133.33	142.22	148.15	151.11	160.00
10	111.11	122.22	133.33	138.89	144.44	148.15	155.56	166.67	177.78	185.19	188.89	200.00
12	133.33	146.67	160.00	166.67	173.33	177.78	186.67	200.00	213.33	222.22	226.67	240.00
14	155.56	171.11	186.67	194.44	202.22	207.41	217.78	233.33	248.89	259.26	264.44	280.00
15	166.67	183.33	200.00	208.33	216.67	222.22	233.33	250.00	266.67	277.77	283.33	300.00
16	177.78	195.56	213.33	222.22	231.11	237.04	248.89	266.67	284.44	296.30	302.22	320.00
18	200.00	220.00	240.00	250.00	260.00	266.67	280.00	300.00	320.00	333.33	340.00	360.00
20	222.22	244.44	266.67	277.78	288.89	296.30	311.11	333.33	355.56	370.37	377.78	400.00
22	244.44	268.89	293.33	305.56	317.78	325.93	342.22	366.67	391.11	407.41	415.56	440.00
24	266.67	293.33	320.00	333.33	346.67	355.56	373.33	400.00	426.67	444.44	453.33	480.00
26	288.89	317.78	346.67	361.11	375.56	385.19	404.44	433.33	462.22	481.48	491.11	520.00
28	311.11	342.22	373.33	388.81	404.44	414.82	435.56	466.67	497.78	581.51	528.89	560.00
30	333.33	366.67	400.00	416.67	433.33	444.44	466.67	500.00	533.33	555.55	566.67	600.00
32	355.56	391.11	426.67	444.44	462.22	474.08	497.78	533.33	568.89	592.58	604.44	640.00
34	377.78	415.56	453.33	472.22	491.11	503.71	528.89	566.67	604.44	629.62	642.22	680.00
36	400.00	440.00	480.00	500.00	520.00	533.33	560.00	600.00	640.00	666.67	680.00	720.00
38	422.22	464.44	506.67	527.78	548.89	562.97	591.11	633.33	675.56	703.70	717.78	760.00
40	444.44	488.89	533.33	555.56	577.78	592.60	622.22	666.67	711.11	740.73	755.56	800.00
42	466.67	513.33	560.00	583.33	606.67	622.22	653.33	700.00	746.67	777.78	793.33	840.00
44	488.89	537.78	586.67	611.11	635.56	651.85	684.44	733.33	782.22	814.81	831.11	880.00

TABLE 207.—MATERIALS REQUIRED FOR 1 CU. YD. OF CONCRETE

Mixture	Cement	Sand	Stone
1–1½–3	1.9 bbls.	0.42 cu. yds.	0.85 cu. yds.
1–2–3	1.7 "	0.52 " "	0.77 " "
1–2–4	1.5 "	0.45 " "	0.90 " "
1–2½–5	1.2 "	0.46 " "	0.92 " "
1–3–6	1.0 "	0.47 " "	0.95 " "

The amount of water used per cu. yd. of concrete will vary greatly. A plastic mixture usually requires about 30 gals. per cu. yd., according to Baker, 40 gals. according to Barnes.

Where boulders are embedded in the foundations and side walls of small culverts similar to Plate 15, less cement, sand, and stone are required; our experience with work of this kind shows that only 0.8 to 0.9 bbls. of cement are needed per cu. yd. for the total amount of concrete in these culverts including cover and parapets. For all classes of work where boulders cannot be embedded these proportions are about right.

Fuller's Rule.—An approximate rule for ready calculation is the one originated by William B. Fuller, and is as follows: Divide 11 by the sum of the parts (by volume) of all the ingredients; the quotient is the number of barrels of Portland cement required per cubic yard of concrete. Multiplying this by the number of parts of sand and of stone will give the number of barrels of each. To reduce barrels to cubic yards, multiply by 0.14 (since a barrel contains 3.8 cu. ft. and there are 27 cu. ft. in a cubic yard).

For example, suppose it is wished to mix a concrete in the proportion 1–3–6. Then

$6 + 3 + 1 = 10.$

$11 \div 10 = 1.1$ bbl. of cement required per cubic yard of concrete.

$3 \times 1.1 \times 0.14 = 0.462$ cu. yd. of sand required per cubic yard of concrete.

$6 \times 1.1 \times 0.14 = 0.924$ cu. yd. of crushed stone required per cubic yard of concrete.

Fuller's rule gives slightly more cement per cubic yard than given in Table 207.

Wastage.—The quantities given by this rule and Table 207 are net quantities and do not allow for waste in unloading, hauling, etc. Wastage of sand and stone will amount to 2% to 10% depending on method of handling.

ABLE 207A.—AMOUNT OF CEMENT AND SAND PER CU. YD. OF MORTARS

Mortar mix	Cement, bbls.	Sand, c. y.
1:1	4.7	0.72
1:1.5	3.9	0.86
1:2	3.2	0.95
1:3	2.4	1.07
1:4	1.9	1.15

Right-of-way Computations.—The form of traverse computation nd closure was shown on page 842.

The areas of rights of way are generally figured by dividing the arcel into rectangles, trapezoids, triangles, sectors, or segments, nd figuring these shapes from the formulas given on page 1576. hese areas are checked by planimeter. They are usually figured the nearest 0.01 acre.

The method of double-meridian distances can, however, be used desired. The following formula and example are given to illusate this method. It is not often necessary and is a tedious mputation.

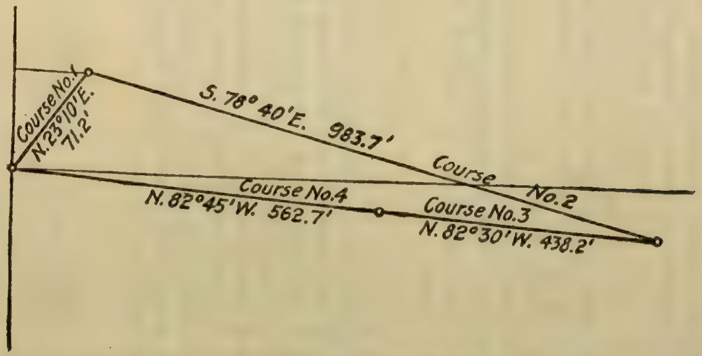
The rule is: *Twice the area of the figure is equal to the algebraic im of the products of the double-meridian distances of each course ultiplied by its latitude*, in which the double-meridian distance quals the sum of the meridian distances of the two ends of each ourse referred to the meridian drawn through the most westerly oint of the parcel, and the latitude of each course is reckoned as lus if the course runs north and minus if it runs south. Take s an example the right-of-way parcel shown in Fig. 276 (p. 842) or which the traverse has been figured, and refer the meridian istances to the meridian drawn through the corner 3.1′ distance om Sta. 194 + 71.7.

Example of Double-meridian Distance Area Computation of the Parcel Shown in Fig. 276 (p. 842), and Fig. given below

Course number	Bearing	Distance	N	S	E	W	Lat.	D.M.D.	+ Areas	− Areas
1	N 23° 10′ E	71.2	65.4	.....	28.0	.....	+ 65.4	28.0	1,831	....
2	S 78° 40′ E	983.7	....	193.3	964.5	.....	− 193.3	1,020.5	.....	197,263
3	N 82° 30′ W	438.2	57.2	.....	.....	434.5	+ 57.2	1,550.5	88,688	....
4	N 82° 45′ W	562.7	71.0	.....	.....	558.2	+ 71.0	558.2	39,632	....

197,263 sq. ft. − 130,151 sq. ft. = 67,112 sq. ft.
This equals twice the area of the parcel.

Area of parcel $= \frac{67{,}112}{2 \times 43{,}560} = 0.770$ acre.



TYPICAL DESIGN REPORT

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Sample Design Report

"Rush-Mendon, Part 1, Road 1392.
Monroe County, New York,
Division Engineer,
Rochester, N. Y.
"Dear Sir:
Find attached design report, Road 1392.

"Considering traffic, soil, and local material conditions, we recommend a 16′ penetration-bituminous-macadam pavement varying in depth from 10 to 20″ and averaging 11″ for the entire road with gravel shoulders, 6 % maximum grade, 301′ minimum radius of curvature, 350′ minimum sight distance, 24 to 32′ width of grading section, 1½ to 1 slopes and cut to fill ratios of 1.10 to 1.30. A satisfactory pavement of this character is estimated to cost approximately $1.60 per square yard for construction, 3.5 cts. per square yard per year for ordinary maintenance and 11 cts. per square yard per year for renewals over a long term of years. The total estimated construction cost is $100,000. The detail report follows:

Detail Report

"**1. Location and Length.**—Proposed Road 1392 extends from Road 1393 to Road 1187, a distance of 3.69 miles. It completes the east-and-west state system in this locality and gives a continuous road from Caledonia to Canandaigua via Scottsville. It is not likely that this route will change the volume of traffic on Route 6 (Canandaigua to Caledonia via Avon), as Route 6 is shorter, but it will serve as a convenient pass during times of reconstruction on Route 6.

"**2. Traffic Classification.**—Road 1392 is on the verge between Classes II and III traffic according to classification map. It will probably carry about 400 to 1000 vehicles daily, which is lower-limit Class II or upper-limit Class III.

"**3. Grades and Alignment.**—The existing alignment is quite good and requires only minor improvements. The existing grades are in the main easy, with a few short steep grades of 8 to 9 %. The new profile, as a rule, follows the existing road closely with short grade reductions. The total rise and fall for the old and new road is about the same. The proposed grading will have some effect on motor operation cost, but is largely useful in providing a convenient width for traffic and a smooth bed for the pavement. In figuring the economic value of the improvement, grade reductions can be given some weight for this road (see accompanying tabulation based on Curve 1, Fig. 2, p. 13). Total grading cost estimated at $32,000. Maximum economic benefit of grading estimated at $18,000.

Comparison Capitalized Motor Operation Cost, Old and New Profile

(Based on Curve 1, Fig. 2, p. 13)

Rate of grade, per cent	Estimated capitalized cost per 100 vehicles daily per foot of distance	Old profile		New profile	
		Length, feet	Amount 100 vehicles daily	Length, feet	Amount 100 vehicles daily
1.0 or less	$ 9.10	8,300	$ 75,430	7,900	$ 71,890
1.5	9.12	800	7,296	400	3,648
2.0	9.15	1,200	10,980	1,700	15,555
2.2	9.17	200	1,834	800	7,336
2.4	9.19	500	4,595	700	6,433
2.6	9.21	600	5,526	300	2,763
2.8	9.23	1,000	9,230	800	7,384
3.0	9.25	800	7,400	1,600	14,800
3.2	9.28	800	7,424	500	4,640
3.4	9.31	500	4,655	500	4,655
3.6	9.34	400	3,736	1,000	9,340
3.8	9.37	100	937		
4.0	9.40	400	3,760	700	6,580
4.2	9.45	300	2,835	200	1,890
4.4	9.50	400	3,800	400	3,800
4.6	9.56	500	4,780	100	956
4.8	9.63	200	1,926	200	1,926
5.0	9.70	300	2,910	100	970
5.2	9.80	100	980	100	980
5.4	9.90	100	990		
5.6	10.00	400	4,000	300	3,000
5.8	10..0	400	4,040	400	4,040
6.0	10.20	....	....	800	8,160
6.5	10.70				
7.0	11.20	100	1,120		
7.5	11.85	500	5,925		
8.0	12.50	300	2,500		
8.5	13.25	100	1,325		
9.0	14.00	100	1,400		
9.5	14.75				
10.0	15.50	200	3,100		
100 vehicles daily total............			$184,534	....	$180,746
500 vehicles daily total............			$922,534	....	$904,000

Maximum economic value of grading $18,000. (922,000 − $904,000)

"4. **Suitable Types of Pavement (Based on Traffic Classification).**—For lower-limit Class II traffic, either penetration bituminous macadam or water-bound macadam oiled is suitable (see Table 13, p. 58). Reinforced cement concrete might be considered under specially favorable conditions of material supply, but for the volume of traffic expected there would probably have to be unusually strong reasons of expediency to warrant consideration of this type. For comparative estimate purposes the cheapest possible type of this pavement will be used (see Fig. 156, p. 454), 7″ uniform depth, 1:2:4 mix, 1.7 cement content, 50-lb. reinforcement per 100 sq. ft. of pavement.

"5. **Soils.**—The subgrade soils are as follows:

Soil on Road 1392

(Named in order of greatest amount of each first)

Station	Soils	Station	Soils
0– 2	Muck	142–154	Loam clay
2– 72	Loam gravel sand	154–157	Loam sand
72–106	Loam gravel	157–160	Loam muck
106–110	Sand loam	160–165	Loam clay
110–126	Loam clay	165–172	Loam sand
126–130	Loam muck	172–181	Clay loam
130–142	Loam gravel	181–194	Loam clay

"**6. Uniform Strength Design (Alternate Pavement Estimates).**—Macadam depths based on Table 153 (p. 959), concrete pavement based on Fig. 156 (p. 454).

Station to station	Soil	Grading conditions	Total pavement depths	
			Macadam, inches	Concrete 1:2:4 mix, 0.5-lb. reinforcement per square foot, inches
0– 2	Muck	Gravel fill 4′	8	7
2– 49	Loam gravel	Light cuts and fills	10	7
49– 51	Loam gravel	Fill 2 to 4′	9	7
51– 72	Loam gravel	Light cuts and fills	10	7
72– 89	Loam gravel	Light cuts and fills	10	7
89– 91	Loam gravel	Fill 2 to 5′	9	7
91–106	Loam gravel	Light cuts and fills	10	7
106–110	Sand loam	Light cuts and fills	9	7
110–112	Loam clay	Fill 2 to 4′	10	7
112–123	Loam clay	Light cuts and fills	12	7
123–126	Loam clay	Fill 2′ deep	11	7
126–130	Loam muck	Light cuts and fills	20	8[1]
130–142	Loam gravel	Light cuts and fills	10	7
142–149	Loam clay	Light cuts and fills	12	7
149–153	Loam clay	Fill 1.5′ deep	11	7
153–157	Loam sand	Light cuts and fills	10	7
157–160	Loam muck	Light cuts and fills	20	8[1]
160–165	Loam clay	Light cuts and fills	12	7
165–172	Loam sand	Light cuts and fills	10	7
172–181	Clay loam	Light cuts and fills	13	7
181–194	Loam clay	Light cuts and fills	12	7

[1] 12-in. gravel subbase under concrete.

Average depth macadam 11″. Use normal 10″ with extra subbase allowance.

Note.—The average of 11″ is liberal, as Road 502 at east end of this road has served same class of traffic with same general soil conditions with a depth of 9″ for the last 10 years with only minor area weakness.

"Road 502 has a 6″ boulder base and a 3″ penetration-bituminous-macadam top.

"We recommend for this road a boulder base 6½ to 16½″ deep laid in layers not exceeding 8″ depth filled with coarse gravel or crushed stone and capped with a 3½″ penetration-bituminous-macadam top.

"**7. Amounts of Material Required.**—There are 37,000 sq. yd. of pavement on this road.

"Macadam type of pavement will require approximately:

7,800 cu. yd. gravel or boulder foundation
3,700 cu. yd. 3½" top course
75,000 gal. bitumen (binder) or
12,000 gal. surface oil

"Concrete pavement will require approximately:

7,250 cu. yd. 1:2:4 concrete
12,300 bbl. cement
166,000 lb. steel
10,000 lin. ft. expansion joints
400 cu. yd. gravel foundation.

"**8. Materials Available.**—For details, see Survey Field Book 1392. A limited supply of local boulder fence stone fit for subbase or crushed bituminous macadam top is available. Unlimited supplies of coarse hard gravel fit for subbase, subbase filler, or concrete are available. Imported materials can be unloaded at Rochester Junction or Rush and delivered with short hauls. Water supply abundant year round from Honeoye Creek.

"For purposes of estimating concrete pavement, use Mead's gravel pit, Sta. 50.

"For purposes of estimating macadam, use local boulder subbase bottom entire length filled with gravel or local crushed stone and capped with 3½" consolidated depth of local granite top, Stas. 0 to 100, and imported limestone top, Sta. 100 to 195. There are 10,000 to 12,000 cu. yd. of boulder available, but in order to get this amount the farmers will insist on bottoms being cleaned up, which will necessitate blasting large granite boulders which can be used to best advantage for local stone top bituminous macadam type. For water-bound macadam, imported limestone will have to be used.

"On this basis, fair comparative preliminary estimates of cost are given in Art. 9. Detail cost figures are on file in estimate book under Road 1392.

"**9. Comparative Cost Estimates.**

Type	Average thickness, inches	Cost per square yard of pavement				
		Estimated construction cost	Yearly interest 5%	Yearly maintenance, Table 97 (p. 520)	Yearly renewal Table 97 (p. 520)	Total yearly charge
Water-bound macadam[1]	11	$1.50	$0.075	$0.065	$0.10	$0.24
Bituminous macadam[2]	11	1.60	0.008	0.035	0.11	0.225
Cement concrete	7	2.30	0.115	0.010	0.12	0.245

[1] Limestone top (oiled).
[2] Part granite, part limestone top.

"Grading, culverts, and incidental items are estimated at $43,000 for al types of pavement.

"Total estimated construction costs for different widths of different type: are tabulated below:

Type of pavement	Widths of pavement					
	8′	10′	12′	14′	16′	18′
Water-bound macadam..........	$70,000	$78,000	$ 85,000	$ 99,000	$ 99,000	$105,000
Bituminous macadam..........	73,000	80,000	88,000	94,000	102,000	109,000
Cement concrete..........	85,000	96,000	108,000	116,000	128,000	138,000

EFFECT OF MOTOR OPERATION ON TOTAL COST OF TYPES TO THE COMMUNITY (Based on Table, p. 551, Chap. VII)

"For a volume of 500 vehicles daily the comparative total yearly charge against the different types proposed is as follows:

Water-bound macadam..	$0.24 +	$0.01 =	$0.25
Bituminous macadam...	0.225 +	0.01 =	0.235
Cement concrete........	0.245 +	0.00 =	0.245

"**10. Reasonable Maximum Expenditure.**—Reasonable expenditures based on reduction in traffic operation cost can be estimated approximately as follows:

"Grade reduction value (Art. 3 of this report) is estimated at not to exceed $18,000.

"Pavement value is roughly estimated as follows: The old existing road is a narrow gravel road in fairly good condition; the new pavement will not probably reduce the cost of operation over 1 ct. per vehicle mile, but it will add materially to the safety and convenience of operation, which are classed as intangible benefits. Actual reductions in operation cost (see Table 7, p. 15) will not probably justify construction expenditures of over $16,000 per mile for 500 vehicles daily, or a total of approximately $60,000. The total maximum economic value, including grading and pavement, does not probably exceed $75,000. Any expenditure over this amount must be charged to convenience, pleasure, and other desirable intangible benefits. This indicates that caution should be exercised in running the cost up needlessly. Article 9 indicates that, in order not to exceed the economic limit, a 10′ width of water-bound macadam is the most feasible solution. A pavement as narrow as this is not in accord with the general highway policy, which is based on a minimum width of 16′ on the score of intangible benefits. We therefore recommend the use of 16′ width of bituminous macadam estimated to cost $100,000. This recommendation seems to be warranted, as this type will satisfy traffic demands without running the construction cost up needlessly and without increasing the total final cost of road, including maintenance, renewal, and motor operation over and above the final cost resulting from the use of a more expensive first-cost pavement.

"**11. Bridges.**—There are no bridges on this road.[1]

"**12. Railroad Crossings.**—At Sta. 91 the road crosses the Rochester branch of the Lehigh Valley R. R. at grade. This crossing is a blind one and has no protection. It is 69 in order of importance in this division for elimination, which means it will not be eliminated for a number of years, but in the meantime it is entitled to better protection than now exists; we recommend the immediate installation of automatic flash signals located on the side of the road outside of the pavement area.[2]

(*Signed*)
Designing Engineer"

REMARKS.—For the interest of the reader, actual procedure on this road was as follows: Plans were first prepared for cement-concrete pavement. Before these were let, the administration changed and the plans

[1] For typical bridge report see p. 327, Chap. IV, and p. 774, Chap. XII.

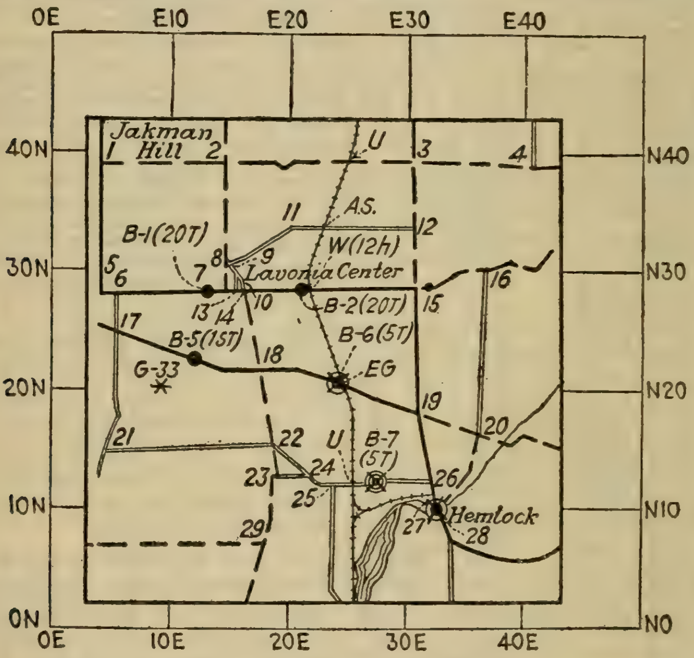
[2] For detailed discussion of grade crossings see Chap. IX.

were revised for bituminous macadam 7″ boulder base, 3″ imported slag middle course, and 2½″ imported limestone top, engineer's estimate of cost, $123,000. The road was constructed on this basis for $102,000 actual contract cost; the pavement proper cost $65,000, or approximately $1.75 per square yard. This final solution was an improvement over the first plans. A careful engineering design could probably have decreased the cost at least $8000 to $10,000 as shown in the body of this report, by a more complete utilization of local materials and more variation in depth to meet varying soil conditions and a somewhat more economical grading design. An automatic signal has recently been erected at the railroad crossing as recommended.

Record Plans and Maps

No generalization can be made as to records except that they must be complete and be kept up to date.

On the completion of construction the original plans are amended to show all construction charges, subgrade soils, depths of pavement



Partial Index of Location of Road Corners

Corner Number	North Coordinate	East Coordinate
1	N 39	E 4
2	N 39	E 14
Etc.	—	—
20	N 16	E 36

Sample record map, showing location of bridges, railway crossings etc.

station by station, etc. Similar plan records are kept for reconstruction so that it is possible to determine subsoil and pavement thicknesses at all points.

Accurate district road maps giving local names and with all road intersections numbered are necessary in order to locate structures, detours, grade crossings, bridges, etc. by a definite designation which can be easily followed in correspondence. The accompanying sketch illustrates a convenient method for such maps.

Similar maps showing location and condition of bridges and grade crossings help materially in laying out reasonable programs. Sample map of this nature is shown on page 1100.

Map Symbols and Legends

Bridges:

Masonry and concrete:

Ample width and strength	●
Narrow but strong	●
Ample width but weak	●
Narrow and weak	●
Safe load in tons-brackets	(5T)

Steel:

Ample width and strength	⊙
Narrow but strong	⊙
Ample width but weak	⊙
Narrow and weak	⊙
Safe load in tons-brackets	(10T)

Wooden:

Ample width and strength	◎

Same symbols for width and strength as for other types.

Railroad Crossings:

U—Unprotected

W.—Watchmen—no. hours (12)

A.S.—Automatic signals.

E.G.—Elimination—good.

E.F.—Elimination—fair.

E.P.—Elimination—poor.

Location of Materials:

×—Sand.

⋇—Gravel.

✳—Stone.

Etc.

Sample number after symbol.

Pavements:

Any symbols desired.

On sample map as follows:

═══earth.

▬ ▬ ▬Gravel.

━━━Macadam.

▀▀▀Concrete.

Explanation of Sample Record Road Map.—The main value of record highway maps is to show the location and general condition of the pavements, bridges, railroad crossings, detours, unloading

points, and local material supplies. After the base map is prepared it is possible by means of various symbols and legends to include any class of information desired.

As a general rule, it is desirable to avoid cluttering the map up too much, which results in separate maps for pavement records, material supplies, bridges, grade crossings, etc. The sample map given includes all these types of information merely to illustrate the value of such maps and is explained as follows:

Detours.—Suppose bridge 6 between corners 18 and 19 is closed for repair and it is desired to indicate the detour by letter or by telephone message. Detour is as follows corner 18-14-15-19 by good gravel and macadam roads.

Bridge Data.—Suppose it is desired to move heavy machinery; such movements can be routed by means of the bridge data and corner numbers.

Grade-crossing Data.—General condition of territory in the matter of protection can be easily visualized by a map bearing these data.

Location of Local Materials.—Gravel pit (official sample G-33) suitable for gravel bottom and top courses but unsuitable for concrete is located N20 East 10.

Requests for Expenditure Authorization.—Location of culverts bridges, etc. can be easily made as follows:

Culvert located 320′ from corner 21 towards corner 22.

Rural Directory Location.—Corner 21 towards 22 (3-R) meaning third house on right side of road.

Any number of other uses desired.

THE LOCATION OF NEW ROADS

Detail instructions compiled by the author for drafting-room procedure in connection with the design of mountain roads.

Notes for Designers on the Preparation of Plans

In the preparation of plans, the quickest and easiest method which will be sufficiently accurate for the purpose should be used.

In this connection, it should be borne in mind that, as a rule graphic methods are to be preferred to computations wherever such methods are sufficiently accurate. This will probably occur in nine cases out of ten.

Considering the methods which will be employed in constructing mountain roads and in staking them out for construction, localized errors in paper locations are not important factors in determining the value of the design.

A localized error in length of 1 or even 2′ per 100′ on one curve will not materially affect the accuracy of the layout or the quantity of excavation, particularly as these errors tend to balance and they are never cumulative.

A localized error of 0.1 or even 0.2′ on the profile grade line will not destroy the value of the plans or the value of the estimate, as it is not cumulative.

Careful graphic methods will not exceed these limits and the average error should be well within the necessary accuracy.

A sample sheet of plan and profile using graphic methods is attached (see p. 1106). This shows a uniform method of procedure which is to be followed wherever, according to best judgment, the method can be used.

Instructions for Drafting Room

It is necessary in drafting-room work to keep all records and computations in as neat and orderly condition as possible.

Have on your desk only as much material as you need for the work you are doing. *Keep the rest in the files.*

At night clean off the tables completely and place your working material either in your table drawers or in the files. Cover tables with cover.

All computations and maps must be marked plainly with the name of the job.

All office computations which will become part of the permanent records are to be made on the forms provided or on letter-sized sheets.

The designing chief for each project will be responsible for the following notations on all records:

Name of job on each separate sheet or roll of computations and plans

Name of computer on each sheet.

Name of checker on each sheet.

The methods employed in all work should be shown in enough detail to make it possible for anyone to check the results.

Drafting-room Supplies

Tracing cloth, plain, 25″ wide	1.7 yd. per mile
Detail paper (36″ wide) (1 lb. = 8′ of 36″ paper)	1/3 lb. per mile
Cross-section paper (opaque) (used for profiles) 22″ wide	1.7 yd. per mile
Transparent cross-section paper (22″ wide)	6 yd. per mile
Cross-section sheets (18 by 24″)	12 sheets per mile

Cost per mile, office supplies, $1.50.[1]

Detail Instructions, Mountain Road Design

These instructions have been prepared in detail, as many of the men have no idea of the order of work or reasonable speeds on the various parts of the design and in many cases they waste time by needless work on the rough plans. The cost of design work is often high on account of the inexperience of the force. By a careful study of these instructions some improvement in speed and cost should be obtained.

[1] 1918 scale of costs.

Speed of Work.—The following list of reasonable speed is based on a 7-hr. working day for the average man. If you are not equaling this rate ask the chief draftsman to see if he can help you find the cause.

General Speed.—Two miles per month per man of completed plans when men are experienced.

About 1¼ miles per month per man when force is not used to road design.

Table 208.—Detail Reasonable Speed

Division of Work		Approximate Miles per Day per Man
1.	(a) Plotting, checking, and inking base line and plotting topography	1.5
	[1](b) Base-line profile complete	3.0
	Computing and checking cross-section notes, 140 sections approx., per day per man	1.5
	[1](c) Plotting and checking cross-sections	1.0
	(d) Inking cross-sections	1.5
2.	(a) Trial grade line	7.0
	[1](b) Projecting grade contour on map	1.5
	(c) Projecting final center line	1.0
3.	[1](a) New center-line profile	1.0
	[1](b) Balanced section profile	1.5
	(c) Trial final grade based on balanced profile	1.5
	(d) Drawing templets on sections	2.0
	(e) Planimeter sections and compute quantities	0.8
	[1](f) Determine final grade line and balance quantities	0.4
	(g) Ink final grade line	7.0
4.	(a) Compiling estimate	2.0
5.	(a) Tracing plans	0.6

[1] Indicates work that can be done to advantage by two men working together.

Reasonable Cost

General Cost Completed Plans	$40 to $50 per mile with experienced men $80 to $100 per mile with inexperienced men

Detail Costs

Based on the following wages:

Designer	$150 per month
Draftsman	110 per month
Tracers	90 per month
Computers	80 per month

1917 SCALE OF COSTS. COSTS IN 1926 ABOUT 80% HIGHER THAN 1917

		Cost per Mile
1. (*a*)	Detailed paper map	$ 2.50
(*b*)	Base-line profile	1.00
	Computing sections	2.00
(*c*)	Plotting and checking cross-sections	3.00
(*d*)	Inking cross-sections	2.00
2. (*a*)	Laying trial grade	1.00
(*b*)	Projecting grade contour	3.00
(*c*)	Projecting final center line	8.00
3. (*a*)	New center-line profile	3.50
(*b*)	Balanced section profile	4.00
(*c*)	Trial final grade based on balanced profile	4.00
(*d*)	Templets drawn on	3.00
(*e*)	Planimeter and computation of quantities	4.00
(*f*)	Determine final grade line and balance quantities	10.00
(*g*)	Ink in final grade line	.50
4. (*a*)	Compile estimate	3.00
5. (*a*)	Trace plans	5.00
	Total	$59.50

STADIA SURVEYS

(Reasonable speeds)

Field work..........400 to 600 shots per day (three-man party)
Office work:
Reducing and checking shots............ 350 shots (two men)
Plotting shots.......................... 500 shots (two men)

Detail Office Design, Manipulation

General Note.—Get all information on rough plans and profiles needed by the tracer, but do not ink anything not likely to be erased during the design and do not attempt to print notes, etc. A great deal of time is being wasted every day by unnecessary work on the rough plans. It is appreciated that good work has been done, but further improvement can be made.

Be careful to mark the name of the road on all rolls, sheets, etc., *before* starting work.

It is not expected that these instructions will be followed absolutely, but the system outlined has been proved in practice and it is expected that you will follow the principles, give the information called for, and that you will eliminate useless work.

1. Preliminary Work. *a.* **Map.**—(See sample map. One man working alone.)

The map is drawn on a roll of detail paper 18″ wide.

Scale 1″ = 100′. In exceptionally hard locations use 1″ = 50′.

Order of Work.—(1) Plot base line in pencil (6H) using vernier protractor or tangent method in plotting angles and careful scaling

for distances between transit points. Plot bearing of each course from north line drawn through each transit point.

(2) Check this plotting.

(3) Ink in the base line with a fine, solid black line and mark the transit points with small circles.

(4) Mark the even stations with a short ink dash and number every fifth station in black ink. Mark station of transit points in black ink.

(5) Mark true bearing or azimuth on each course in black ink and check.

(6) Show the location of each cross-section by a fine red-ink line extending far enough from the base line to reach any center line shift and check. Do this work very carefully as your center-line distances will be affected.

(7) Plot topography in pencil (4H) making the lines heavy and firm so it can be easily traced without inking. *DO NOT INK.* Write all notes, property names, etc., in large plain longhand. *DO NOT PRINT.* Use 4H pencil with a blunt point so tracer can read easily.

b. **Base-line Profile.**—(See sample profile.)

Use heavy white paper roll 22″ wide ruled in squares 10 to the inch.

Scales.—Use 1″ = 100′ horizontal or 1″ = 50′ horizontal to agree with the map scale. Use 1″ = 10′ vertical.

Order of Work.—(1) One man mark even stations in pencil along upper margin. Use 4H pencil with blunt point and make the figures large and distinct, but don't be fussy.

(2) (Two men.) One man calling from notes. Other man write in pencil on profile the elevations of base line at even stations and pluses.

Record these elevations in tens, units, and tenths. Do not record hundreds and thousands. These can be easily determined by the datum on the profile and their omission saves time.

Also, write pluses of stationing on margin. Use 4H pencil, large plain figures, but do not be fussy. Check back these figures.

(3) (One man.) Plot profile points by referring to elevations marked in pencil. If reasonable care is taken in plotting, this need not be checked.

(4) Ink in ground line with light, firm black-ink line.

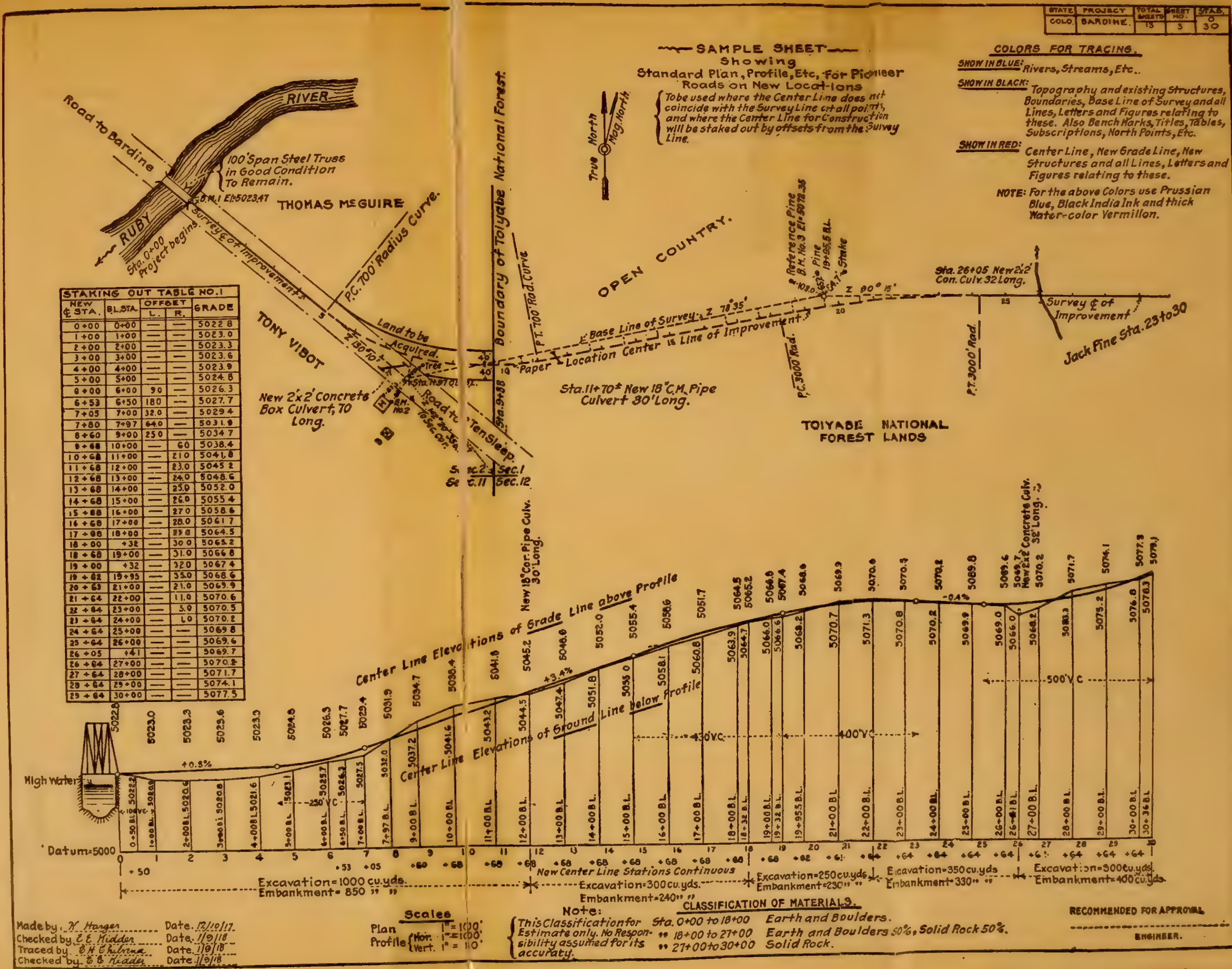
c. **Cross-sections.**—(See sample sheet.)

Plot on transparent cross-section paper cut in sheets 22 by 36″ and ruled 1″ = 10 parts or 1″ = 5 parts heavy and 5 subdivisions lighter.

Scale.—Use 1″ = 5′ except for exceptionally heavy work when 1″ = 10′ may be used.

Elevations.—Points must be plotted by their absolute elevation referred to the datum used for the bench levels. The heavy lines outlining each square inch must be used as an even 5 or 10′ of absolute elevation.

Order of Work.—(Two men work together.) (1) Mark base-line verticals and use same vertical for all sections in each row. Generally two rows of sections can be placed on each sheet.



STAKING OUT TABLE NO. 1

NEW ℄ STA.	B.L. STA.	OFFSET L.	OFFSET R.	GRADE
0+00	0+00	—	—	5022.8
1+00	1+00	—	—	5023.0
2+00	2+00	—	—	5023.3
3+00	3+00	—	—	5023.6
4+00	4+00	—	—	5023.9
5+00	5+00	—	—	5024.8
6+00	6+00	90	—	5026.3
6+53	6+50	180	—	5027.7
7+05	7+00	32.0	—	5029.4
7+80	7+97	64.0	—	5031.9
8+60	9+00	250	—	5034.7
9+68	10+00	—	60	5038.4
10+68	11+00	—	210	5041.8
11+68	12+00	—	23.0	5045.2
12+68	13+00	—	24.0	5048.6
13+68	14+00	—	25.0	5052.0
14+68	15+00	—	26.0	5055.4
15+68	16+00	—	270	5058.6
16+68	17+00	—	28.0	5061.7
17+68	18+00	—	[illegible]	5064.5
18+00	+32	—	30.0	5065.2
18+68	19+00	—	31.0	5066.8
19+00	+32	—	320	5067.4
19+82	19+95	—	35.0	5068.6
20+63	21+00	—	21.0	5069.9
21+64	22+00	—	11.0	5070.6
22+64	23+00	—	5.0	5070.5
23+64	24+00	—	1.0	5070.2
24+64	25+00	—	—	5069.8
25+64	26+00	—	—	5069.6
26+05	+41	—	—	5069.7
26+64	27+00	—	—	5070.2
27+64	28+00	—	—	5071.7
28+64	29+00	—	—	5074.1
29+64	30+00	—	—	5077.5

FIG. 322.

(*Between pages* 1106 *and* 1107.)

(2) Plot ground-line section points by dot surrounded by small circle and write in pencil, vertically, on the base line the elevation of the ground at the base line. Write on the right-hand margin directly opposite and level with the intersection of the ground line and base line, the base-line station and note it as B. L. Sta. 123 + 20.

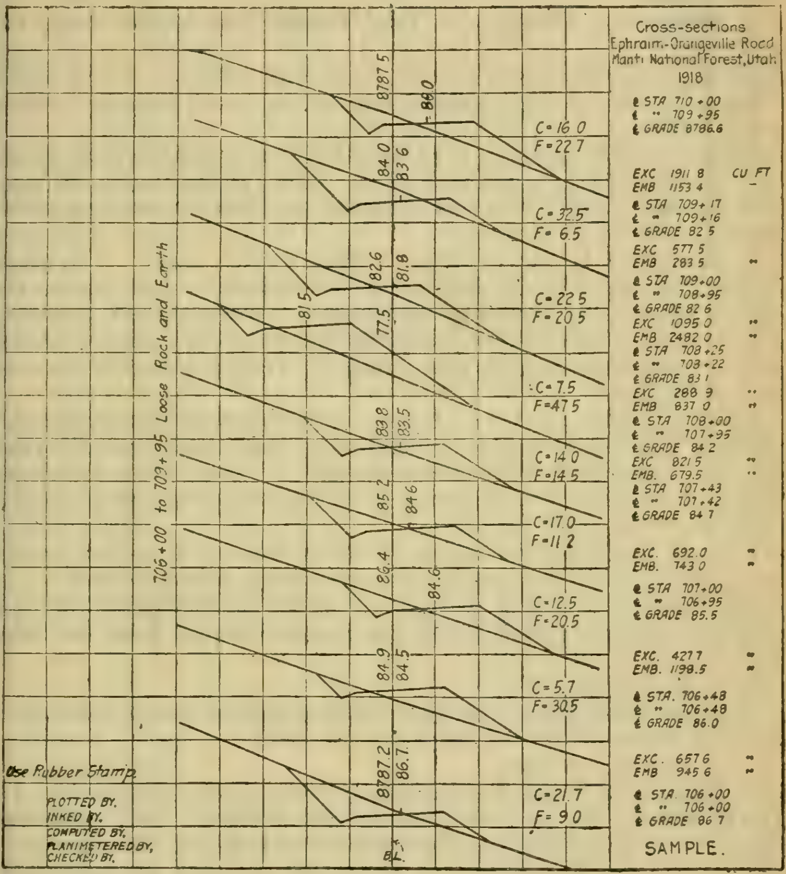


FIG. 323.

(3) Check all operations of plotting and recording by reading back from the actual plotted elevations. No corrections need be made for errors of 0.1′. Correct for any larger errors. It is extremely important that the cross-sections be accurately plotted and carefully checked, as the design depends more on this phase of the work than on any other part.

Elevation and distances farther than 40′ from B. L. should be written in pencil, *viz.*, $\frac{37.6}{45}$ $\begin{matrix}\text{Elev.}\\ \text{Dist.}\end{matrix}$

d. **Inking Cross-sections.**—(One man.) Ink in checked pencil cross-sections.

Use firm, moderately heavy line (black ink) for the ground line.

Use large black-ink heavy-line letters and figures in marking base-line elevations and station numbers.

NOTE.—*The cross-sections must be inked before they are used in the design.*

3. **Grade-line Design.** *a*. **Trial Grade Line.**—(One man, the designer.)

On the base-line profile draw on a trial grade in pencil (6H), using fairly long straight grades and cutting every bump and filling every hollow.

Remember that the object of the trial grade is to smooth out the profile on side-hill work by center-line shift. It is fundamentally different from the final grade line which endeavors to follow the new center-line profile as closely as possible.

b. **Projecting Grade Contour on Map.**—(Two men.) The grade contour should only be determined on side-hill work where the center line can be shifted to advantage. *Designers are cautioned not to use the grade contour method in flat or rolling country. Never destroy good alignment in easy country. It is preferable to use an undulating grade.*

Order of Work.—1. On each cross-section determine the distance right or left of the base line where the trial grade-line elevation for that particular section hits the ground line. Locate this by means of the absolute elevation of trial grade determined graphically from the grade profile.

Do not determine this point by the method of base-line profile, cut or fill as this latter method introduces more chance of error.

(2) Note the location of these points by a light pencil vertical dash and write in pencil lightly the number of feet from the base line.

(3) *Check this work.*

(4) Plot these points on the detail map and mark them by a pin hole surrounded by a small red-ink circle.

(5) *Check this plotting.*

c. **Projecting Final Center Line.**—(One man, designer.) (1) Draw on map the proposed center line in pencil (6H), following as closely as possible the grade contour marked with the red circles, considering the limitations of alignment imposed by reasonable engineering considerations and the type of road desired. This work should be very carefully studied and is a slow operation. The curves should be drawn with the standard office curves or compass and their radii noted in pencil. The approximate locations of the P. C.'s and P. T.'s should be shown by short pencil lines perpendicular to the tangent. If possible, short tangents should separate curves, but this limitation must be used with judgment and is not intended to apply to extremely difficult or costly locations.

Make this projection with sufficient care so that the center line is practically settled on at this point of the design. *This is important.*

(2) Mark the even stations on the new center line continuously by scaling. Use a standard scale on the tangents and the stepping method with dividers on curves. *Check this. Do not use the stepping method on tangents, as it generally introduces a cumulative error.* Number every fifth station plainly in large figures.

(3) Mark lightly in pencil the new center-line stationing where each base-line cross-section line previously drawn in red on the map intersects the new center line. *Check this.*

(4) Mark lightly in pencil at each of these cross-sections the distance from the new center line to the base line and *check this.* You are now ready to transfer the location of the final center line to the cross-sections and plot the final center-line profile.

3. *a.* **New Center-line Profile.** (Two men.) *Order of Work.*—(1) Mark on cross-sections with a short vertical distinct pencil arrow the location of the adopted center line determined by the previously scaled and noted offset marked on the plan. *Check them.*

(2) Directly under the noted base-line station on the right-hand margin of the cross-section sheet write in pencil the new center-line station for each corresponding base-line station as previously determined and shown on the map. *Check this.*

(3) Mark in pencil the absolute elevation of the ground at the new center line. *Check this.*

(4) Plot the true center-line profile, using the true center-line horizontal distances and stationing, the true center-line ground elevations as shown on the cross-sections and showing (as per sample profile) the equivalent B. L. stationing at each section. *Use the same manipulation methods as regards pencil and ink as described for base-line profile.*

b. **Balanced Section Profile.**—(Made by designer and one helper.)

NOTE.—At this point eliminate from all further consideration the base-line profile and trial grade. A great many men attempt to make the final grade similar to the trial grade, which is absolutely the wrong principle, except where a ruling grade governs.

Order of Work.—(1) Select the templet suitable to the cross-section under investigation.

(2) Shift this templet up and down (with the center line always coinciding with the final center-line location previously marked on the cross-section) till it reaches a point where by inspection you judge that the cut area will make the fill area as shown. Mark the center-line elevation of the templet lightly in pencil with a short horizontal dash and write lightly the absolute elevation of this dash.

(3) Plot the center-line elevations of these balanced templets on the new center-line profile for each section by a pencil dash, using the absolute elevation previously determined. *Do not plot by plus or minus from the ground line, as this introduces more chance of error.*

(4) Check this plotting very carefully.

(5) Ink the short dashes with red ink but do not connect these points.

NOTE.—This portion of the work is very important, particularly on a fairly uniform profile. By the use of these balanced templet elevations the final grade can generally be balanced with less work,

shorter hauls, and from 10 to 30% less excavation than if a hit-or-miss method based on ground line is used. The value of this part of the design cannot be over-emphasized. On an extremely rough profile requiring a succession of heavy cuts and fills it is not applicable nor advised.

c. **Trial Final Grade Based on Balanced Templet Elevation.**—(Designer must do this personally.)

Order of Work.—(1) Lay grade line on center-line profile (in fine pencil 6H) following as nearly as possible the balanced elevations shown by the red dashes previously plotted on the profile.

Except where a ruling grade is encountered or where a tangent grade will hit the majority of the indicated balanced elevations, a rolling grade is to be preferred. This can be laid out most economically by a succession of vertical curves selected to fit the conditions. These curves are drawn on the profile by the standard office railroad curve templets and the radius noted. There is no necessity of drawing the tangent grades to intersection, as all the elevations on the vertical curves can be determined graphically. The tangent rates of grade should be laid out to some even tenth and figured between the ends of the vertical curves.

(2) Determine elevations of grade line at each point where a section occurs and write this elevation in heavy pencil above the grade line. Do not record hundreds or thousands in these elevations. Determine these elevations graphically on vertical curves and by figuring on tangent grades.

(3) *Check these elevations.*

(4) Transfer each elevation to the cross-sections by recording it in pencil directly under the center-line stationing on the right-hand margin of the sheet. *Check this transfer.*

d. **Drawing in Templets.**—(Designer should do this.)

NOTE.—This work should be done by the designer, as considerable judgment must be exercised in the selection and variation of the standard sections.

Order of Work.—(1) Draw in proper templet making its center-line elevation agree with grade elevation previously recorded under the station number. Use a 4H pencil with a fine point, as many of these templets will have to be changed before the design is accepted.

e. **Planimetering Areas.** *Methods.*—Various methods can be used, depending on the kind of planimeter. So long as care is taken and a double run is made to check the initial run any desired method will be satisfactory.

With a fixed-arm planimeter reading directly to square inches a double run divided by 8 is the usual practice for a 5′ scale.

With an adjustable-arm planimeter it can be set to read square feet directly on the second run or can be set to read cubic yards per 100′ directly. The last method is a great time saver.

Order of Work.—(1) Check the correctness of templet plotting by comparing templet elevation with grade elevation marked on the margin. *The planimeter man is responsible for checking the templet plotting.*

(2) Test planimeter before using and at frequent intervals to see it is recording correctly.

(3) Planimeter the areas checking by a double run.
(4) Record the areas of cut and fill in pencil at the right of the sections to nearest foot as C = 21

F = 20.

Computation of Grading Quantities. Order of Work.—(1) (Two men.) Transfer center-line stationing and areas for each cross-section to the standard computation sheets. *Check this transfer.*

(2) (One man.) Compute quantities. If areas are in square feet compute quantities in cubic feet. *This is an order; no discretion is allowed.* The reason this is specified is because it has been determined from practice that it is quicker and more accurate. The more or less prevalent method of computing each quantity in yards will not be allowed. The use of cubic feet keeps all work in full units and eliminates 90% of the transfers, feet to yards. From checking it has been proved that too many mistakes are made in the decimal point on detail yardage quantities.

(3) *Check Detail Computations.*—This means check every phase of the computations, *distances* between sections, extensions, additions, etc.

f. **Balancing Final Grade Line.**—(Designer and one helper.) This portion of the design is very slow and requires more judgment than any other feature.

(1) It is desirable to balance in as short sections as possible, as this results in cheaper excavation methods. A continuous balance means plow and road machine turnpiking, which is very cheap.

Short balances mean scraper longitudinal haul and machine finish, which is moderately cheap.

Long balances mean wagon haul, which is expensive.

(2) It is desirable to balance with a downhill haul on noticeable grades.

(3) It is desirable to proportion the cut to fill so that dirt is not wasted.

This last is entirely a matter of judgment.

If the ground is bare and classed as common the following ratios will not be far out:

Volume of Excavation per Station	Ratio Cut to Fill
30–50 yd.	1.30:1.25
60–100 yd.	1.25:1.18
Above 100 yd.	1.15:1.10

If the ground has a thick carpet of humus or a heavy stand of large trees the grading conditions cannot be definitely determined until the clearing and grubbing are completed. In such a case the grade line should be noted as tentative and the resident engineer on construction will have to recross-section and redesign the grade after the mold and stumps are removed. The quantities in such a case can only be approximated and should be made on the safe side.

(4) In balancing quantities it is usually desirable to reduce the larger quantity.

(5) It is often cheaper and more desirable to waste at places and borrow at others. This should be borne in mind. The ratio of borrow excavation from pits to borrow fill is generally taken at 1.10.

(6) In considering rock cuts and fills use Trautwines' figures—1 cu. yd. solid rock makes approximately 1.7 cu. yd. rock fill. Where the fill is a mixture of earth and rock, 1 cu. yd. rock will make 1 cu. yd. of fill. The order of work and detail manipulation for the portions of the grade line that have to be changed to accomplish a balance are the same as for the original grade line.

g. **Inking Final Grade.**—After the grade line is balanced, ink it in with red ink on the profile so it can be easily traced.

4. **Estimate.**—(Designer.)

(1) *Drainage.*—From survey notes locate culverts on profile and draw them on the proper cross-section to determine length and invert elevations and outlet ditches if necessary. Do this work in pencil. Make notes clear and complete.

(2) *Bridges.*—Use standard designs up to 25′; above that have design made by department bridge designer.

(3) *Compilation.*—Compile data on forms provided, using center-line station to locate all structures quantities, etc.

(4) Unit costs will be determined by the office engineer in charge of the drafting room and reviewed by the district engineer.

(5) **Check all operations.**

5. *a.* **Tracing Plans.**

Size of Sheets:

Outside 22″ by 36″
Border ½″ top, bottom, and right.
2″ binding edge on left.

All work in black ink.
Make heavy and plain.
Lay out as per sample sheet.
Check all tracing.

b. **Finishing Cross-section Sheets.**—Do not ink in final grade, templets, or center-line ground elevation till contract is let and cross-section blueprints are needed in the field. This delay is advisable, as it is often necessary to revise even after the original design has been accepted.

Explanation of Table of Relative Weights of Office Design

To obtain the equivalent mileage of completed office design multiply the actual mileage complete to date of each subdivision of the work by the percentage shown. Add all these products which will give you the total equivalent mileage of completed design.

Example.—Suppose at the time a report is due you have 10 miles of map completed, 20 miles of base line done, and 5 miles of cross-sections plotted, checked, and inked.

TABLE 209.—ILLUSTRATIVE TABLE FOR DETERMINING THE PERCENTAGE OF COMPLETION OF OFFICE WORK FOR WEEKLY OR MONTHLY PROGRESS REPORTS

Relative Weights Office Design

Pioneer

	Per Cent. of Total Completed Plans
1. *Preliminary Work* (20% of Complete Plans):	
(*a*) Plotting map, checking and inking base line	5%
(*b*) Plotting, checking and inking base line profile	2%
(*c*) Plotting and checking cross-sections	10%
(*d*) Inking cross-sections	4%
2. *Final Center Line* (15% of Complete Plans):	
(*a*) Lay trial grade line on base line profile	1%
(*b*) Project trial grade line contour on map	4%
(*c*) Project final center line location on map	10%
3. *Final Grade Line* (50% of Complete Plans):	
(*a*) Make new center line profile on true center line elevations and distances, ink and check. (NOTE: At this point eliminate trial grade from all further consideration.)	7%
(*b*) Spot elevation of balanced cross-sections on new profile	5%
(*c*) Lay final grade line based on balanced section profile	5%
(*d*) Draw in templets	3%
(*e*) Planimeter and compute quantities and check	10%
(*f*) Balance quantities by grade line shift	19%
(*g*) Ink in final grade line	1%
4. *Compile Estimate* (5% of Complete Plans)	5%
5. *Trace Plans* (10% of Complete Plans)	10%
	100%

This work will be equivalent to the following mileage of complete office design:

Item	Miles
1. (*a*) Map 10 miles × 5%	0.50
1. (*b*) Base-line profile 20 miles × 2%	0.40
1. (*c*) Cross-sections plotted and checked 5 miles × 10%	0.50
1. (*d*) Cross-section inked 5 miles × 4%	0.20
Equivalent miles total completed plans	1.60

Suppose the project is 20 miles long.
The per cent completion office design is 1.6/20 = 8% complete.

Basis of Table of Relative Weights Office Design. *General Speed.*—Two miles per month per man of completed plans when men are experienced.

About 1¼ miles per month per man when force is not used to road design.

Assumed Speed per Man per Day on Various Divisions of Work

		Miles	
1.	(*a*)	1.5	Detail map
*	(*b*)	3.0	Base-line profile
*	(*c*)	1.0	Cross-sections plotting and checking
	(*d*)	1.5	Inking cross-sections
2	(*a*)	7.0	Trial grade
*	(*b*)	1.5	Grade contour
	(*c*)	0.8	Center-line projection
*3.	(*a*)	1.0	Center-line profile
*	(*b*)	1.5	Balanced section profile
	(*c*)	1.5	Final grade line
	(*d*)	2.0	Templets
	(*e*)	0.8	Planimeter and quantities
	(*f*)	0.4	Balance quantities
	(*g*)	7.0	Ink final grade line
4.		2.0	Compiling estimate
5.		0.7	Tracing plans

*Indicates work that can be done better by two men working together which will result in twice speed shown.

SAMPLE ESTIMATE FORMS

SHEET NO.............

ESTIMATE SHEET (LETTER SIZE)

Road............................ Computed by............................

Date............................ Checked by............................

GENERAL SUMMARY			
ITEM	QUANTITY	UNIT PRICE	ESTIMATED COST
			$
Length......miles Cost per mile...............	Total cost of Items $ = +10% for Eng. Adv. & Cont.= Cost to date for Surveys & Plans = Appropriation, =		

SHEET NO.............

ESTIMATE SHEET

Road............................ Computed by............................

Date............................ Checked by............................

SUMMARY CLEARING & GRUBBING						
STATION TO STATION	LENGTH	WIDTH	ACRES	CLASSIFICATION	PRICE PER ACRE	ESTIMATED COST
Totals						
	Average Unit Price per Acre					

SHEET NO.________

ESTIMATE SHEET

Road________________________________ Computed by________________
Date________________________________ Checked by_________________

SUMMARY BORROW			
SOURCE OF SUPPLY STATION	WHERE USED STATION TO STATION	HAUL DISTANCE IN STAS.	QUANTITY CUBIC YARDS

SHEET NO.________

ESTIMATE SHEET

Road________________________________ Computed by________________
Date________________________________ Checked by_________________

SUMMARY OVERHAUL				
LOCATION OF CUT	LOCATION OF FILL STATION TO STATION	NUMBER CUBIC YDS.	LENGTH OF HAUL LIN. FT.	AMOUNT OF OVERHAUL IN STATION YARDS

SHEET NO.-------

ESTIMATE SHEET

Road---------------------------Computed by-------------------

Date---------------------------Checked by-------------------

SUMMARY CONCRETE STRUCTURES											
					CLASS OF CONCRETE			METAL REINFORCEMENT			
STATION	STRUCTURE	LENGTH	EXCAV.	BACK FILL	1ST CU. YDS	2ND CU. YDS	3RD CU. YDS.	MESH LBS.	BARS LBS.	DOWELS LBS.	PAVING

SHEET NO.--------

ESTIMATE SHEET

oad------------------------Computed by------------------------

ate------------------------Checked by------------------------

SUMMARY PIPE CULVERTS														
			CONCRETE PIPE				CORRUGATED				VITRIFIED			
			LENGTH, LIN.FT.				LENGTH, LIN.FT.				LENGTH, LIN.FT.			
TATION	EXCAV.	BACK FILL	18″	24″	30″	36″	15″	18″	24″	30″	12″	15″	18″	24″

SHEET NO.........

ESTIMATE SHEET

Road........................Computed by......................

Date........................Checked by.......................

SUMMARY MASONRY STRUCTURES						
STRUCTURE	STATION TO STATION	LENGTH LIN. FT.	EXCAV. CU. YDS.	BACK FILL CU. YDS.	DRY RUBBLE CU. YDS.	MASONRY RUBBLE CU. YDS.

QUANTITY SHEET

No.....

Road........................Computed by..........Date.......

Section.....................Checked by...........Date.......

CLASSIFICATION	STATION	DIST.	AREAS-SQ. FT.		VOLUME — CUBIC FEET		COMMON
			CUT	FILL	CUT	FILL	EXCAV. CU. FT.

CHAPTER XV

'YPICAL COST ESTIMATE FORMS, COST DATA, AND EQUIPMENT

The cost data given in this chapter have been gathered since 907 and cover most of the items necessary for estimating the ost of ordinary rural highway improvements and small span bridges. ;ach statement of cost gives the labor rates and the conditions of 'ork or the year performed. There has been a large rise in general ost standards 1910 to 1926 and Fig. 324 will help coordinate present osts with the examples given.

Cost data must be used intelligently in order not to be misleading. ocal conditions always govern, and in presenting cost data the eader is cautioned to compare conditions to be met with the conitions described in the data given. The cases given have been elected to represent average costs. A well-equipped efficient orce can often do the work cheaper than shown, while inexperienced men will run the cost up above the amounts shown.

The most common mistake in figuring cost is to underestimate ie overhead charges caused by insurance, liability, plant depreciaon, interest on idle machinery, etc. These items are quite thorughly discussed on pages 1231 to 1270. Net profit is a variable mount depending on the size of contract and the type of bidder be interested.

Percentage of net profit should be larger for a small job than r a large job. Where large state or municipal programs are in rogress, sufficient profit must be allowed to interest large organiations which will get the work out rapidly. For small slow town oad jobs, less profit is necessary, as this class of contractor is tisfied with less yearly income. For most state road programs profit item on 5 miles of road (average length of contract) which ill insure a reasonable year's income for the class of contractors esired is a fair basis of estimate.

This chapter will give standard estimate forms for the usual road ems based on 1926 cost conditions as given on page 1125 followed y detail cost data from which they were derived, and plant, equipnent and other sources of overhead expense.

Explanation of Price (Fig. 324) Eng. News Record.—The dotted ortion of the steel curve represents wrought-iron I-beams at the ittsburgh mill, which in 1885 reached $3.12 per 100 lb., a price ily slightly below the cost of structural steel at Pittsburgh in 1917.

Portland cement when first placed on the market in 1879 was igher in price than it is today, and until 1882 remained higher than r any year except 1920. In 1879, however, cement was sold in

wooden barrels as compared with the present system of calling four 94-lb. sacks a barrel of cement. Until as late as 1907 a single wooden barrel of cement cost about 30 cts. more than a barrel consisting of four sacks. The 1874 to 1879 quotations are for Rosendale cement.

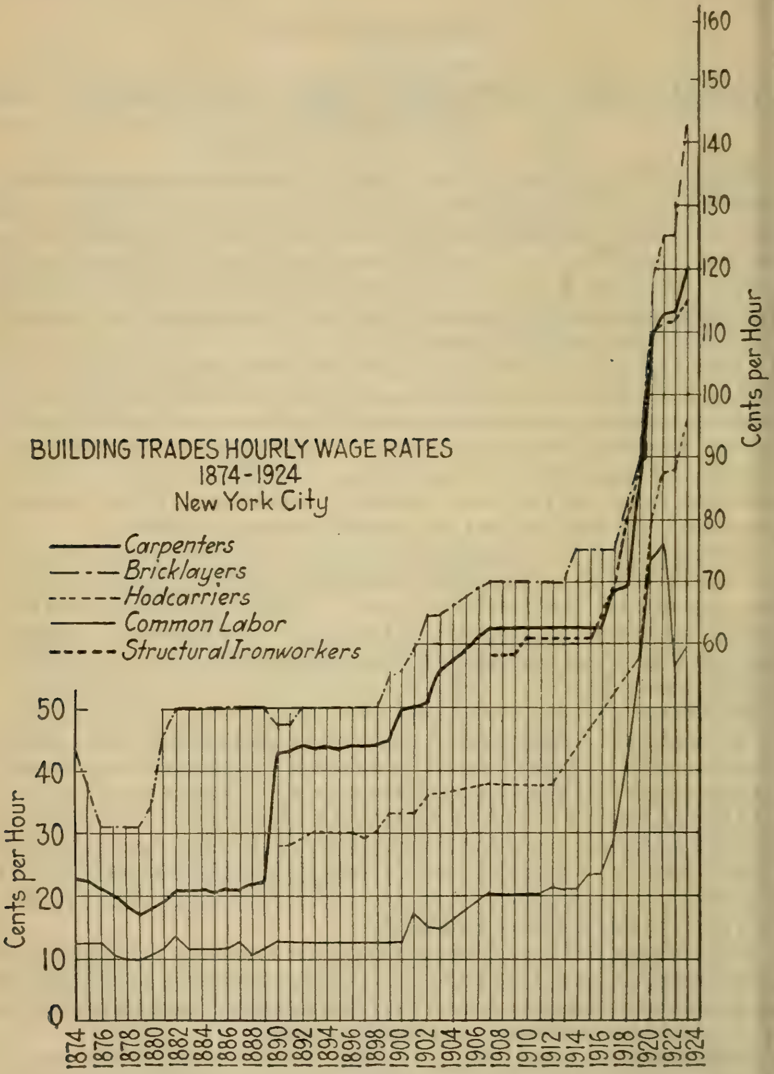


FIG. 324A.

The lumber prices from 1874 to 1909, inclusive, are for long leaf yellow pine boards, 1 by 12"; from 1910 to date for long-leaf yellow pine timbers, 3 by 12"; all per M ft., b.m., in approximately

o' lengths. In 1912 pine lumber prices had reached a point not ouched again until 1918. The slump, which occurred meantime, eached the lowest point between 1914 and 1915. It was caused y the opening of the Panama Canal, when Douglas fir shippers on ne west coast could send the lower-priced lumber through to the tlantic seaboard in competition with southern pine.

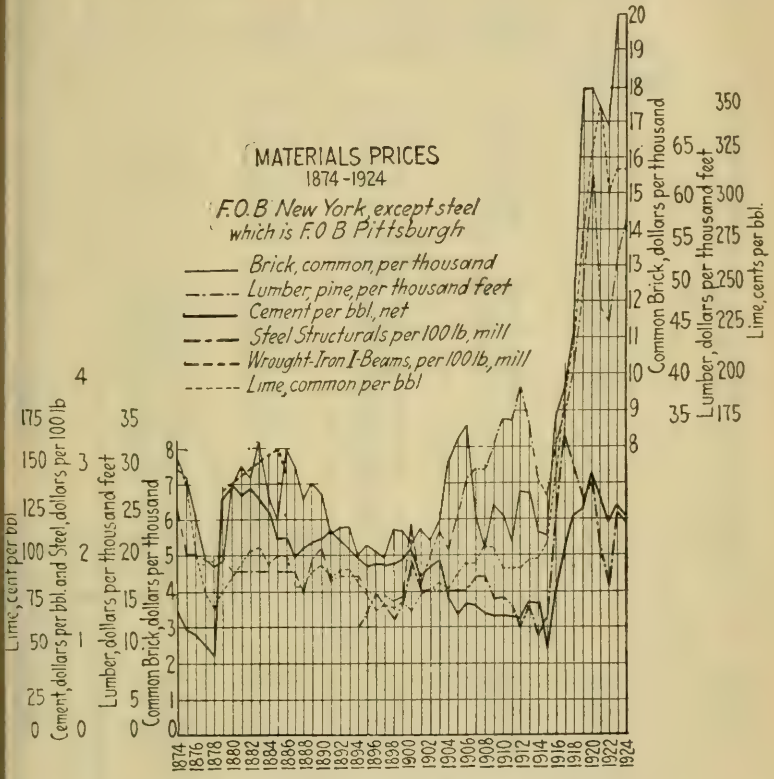


FIG. 324*B*.

The pig-iron curve from 1874 to 1897 inclusive, covers No. 1 oundry Southern. From 1898 to date prices are for No. 2 foundry outhern, with the following exceptions: No. 1 foundry Southern used for 1905 and No. 2 foundry Northern for the year 1912. he price difference between the grade is only 25 to 50 cts.

In September, 1918, prices of building materials were fixed by ne War Industries Board of the United States Government. his action controlled foreign government purchases as well as omestic buying. The ban was lifted in March, 1919.

The lime prices here given are for a "large barrel" (280 lb.).

TABLE 210.[1]—(FIG. 324A).

Comparison of basic building materials prices—1874 to 192[illegible] Average yearly prices, wholesale to dealers or contractors, i[illegible] carload lots, f.o.b. New York, except in the case of ste[illegible] structurals, which are f.o.b. Pittsburgh.

	Pig iron No. 1 fdry. anthracite, per gross ton	Brick common building, per M.	Cement Rosendale, per bbl.	Lime common, per bbl.	Lumber yellow pine 1-in., per M. ft. b.m.	Wrought iron I-beams, channels etc., per 100 lb.
1874	$30.25	$7.41	$1.48	$1.50	$26.00	
1875	25.50	7.12	1.25	1.40	21.00	
1876	22.25	5.87	1.20	1.00	21.00	
1877	18.88	4.93	1.10	.80	20.00	
1878	17.63	4.71	.95	.70	20.00	
			Portland, per bbl.			
1879	18.03	4.08	2.70	.80	20.96	$2.78
1880	28.50	7.00	2.88	.87	19.00	
1881	25.12	7.50	2.72	.95	19.00	
1882	25.75	7.12	2.82	1.01	19.00	
1883	22.38	8.28	.....	1.05	19.00	
1884	19.88	6.65	2.60	.95	19.00	
1885	18.00	6.10	2.28	1.00	18.66	3.12
1886	18.71	7.51	2.28	1.00	19.00	3.00
1887	20.92	7.43	2.07	.82	19.00	
1888	18.88	6.50	2.16	.83	16.75	
1889	17.75	7.06	2.23	.92	20.31	
1890	18.40	6.65	2.25	.95	21.75	
1891	17.52	5.53	2.38	.87	18.00	
1892	15.75	5.77	.....	.93	18.50	
1893	14.52	5.83	.....	.93	18.50	
						Structural ste[illegible] f.o.b. Pittsburgh
1894	12.75	5.00	.....	.85	18.50	1.20
1895	11.50	5.31	1.97	.78	16.92	1.35
1896	12.50	5.06	2.00	.69	16.42	1.60
1897	12.10	4.94	1.97	.72	16.44	
	No. 2 fdry. southern					
1898	10.75	5.75	2.00	.70	15.75	1.27½
1899	15.50	5.69	2.05	.75	16.25	1.45
1900	22.00	5.25	2.16	.68	24.50	1.95
1901	14.37½	5.77	1.89	.77	17.50	1.60
1902	17.25	5.39	1.95	.81	21.00	1.60
1903	22.37½	5.91	2.03	.79	23.50	1.70
1904	13.75	7.50	1.67½	.80	21.50	1.60
1905	17.89	8.10	1.43	.89	24.92	
	(No. 1)					
1906	17.75	8.55	1.55	.95	29.33	1.60
1907	26.25	6.16	1.55	.95	30.50	1.75
1908	16.50	5.10	1.46	1.05	30.50	1.76
1909	15.50	6.39	1.41	1.05	33.04	1.50

[1] Engineering News Record.

TABLE 210.—*Continued*

	Pig iron No. 1 fdry. anthracite, per gross ton	Brick common building, per M.	Cement Rosendale, per bbl.	Lime common, per bbl.	Lumber yellow pine 1-in., per M. ft. b.m.	Wrought-iron I-beams, channels, etc., per 100 lb.
					Long-leaf yellow pine 3-in.	
1910	17.10	6.12½	1.43	.92	36.00	1.52½
1911	15.37½	5.31	1.43	.92	36.00	1.42½
1912	14.75 (Norh.)	6.75	1.34	.92	40.00	1.20
1913	16.43½	6.75	1.58	.97	35.25	1.46
1914	14.56	5.60	1.58	.97	29.50	1.11
1915	15.29	5.50	1.04	1.06	27.75	1.33
1916	22.20	8.69	1.62	.....	32.62	2.48
1917	33.75	9.40	2.16	.....	37.33	3.39
1918	39.90	10.98	2.53	2.21	42.66	3.00
1919	39.01	17.90	2.63	2.65	50.87	2.61
1920	47.73	18.00	3.00	3.18	63.73	2.79
1921	38.28	17.40	2.73	3.49	48.16	2.05
1922	30.77	16.91	2.45	3.00	47.05	1.69
1923	32.12	20.00	2.66	3.12	55.22	2.50
pr. 24 1924	28.00	20.00	2.55	3.12	58.00	2.40

Explanation of Labor Rates (Fig. 324.)—Wages in the building ıdes began to ascend definitely between 1899 and 1907. From ıt period until the war years the curves are generally flat. The ıring began in 1917. At present, wage rates of the skilled trades New York are the highest in the half-century. Common labor ›pped 14½ cts. in value (to 59½ cts.) in 1922, and now stands 60½ cts.

Bricklayers began the 8-hr. day in 1872, as against 10-hr. formerly, d changed from the 48-hr. week to the 44-hr. in 1899. Then, as w, the bricklayers were first to gain labor advantages. That ges in this craft were usually in advance of most of the other des during the last 50 years is shown in the chart. Hod carriers gan the 44-hr. week in 1900.

Carpenters were working 10 hr. per day in 1874, changing to 8 in 1890. The 44-hr. week began in 1900.

Common laborers (excavating) changed from the 10-hr. to the ır. day in 1890. Since 1919 the 8-hr. day has been in force.

Wages remained at the high rates reached in the latter part of 20 and the first part of 1921, throughout 1922. Skilled building des' wage schedules remained unchanged during the 1921 pression despite widespread unemployment.

TABLE 210.—(FIG. 324*B*).—*Continued*

Building trades wage rates—1874 to 1924

New York, per hour

	Carpenter's 10 hr. day	Bricklayers' 8 hr. day	Hod-carriers	Common laborer's 10 hr. day	Structural-iron workers
1874	$0.23	$0.43	......	$0.14	
1875	.22½	.37	......	.14	
1876	.21	.31	......	.14	
1877	.20	.31	......	.12	
1878	.18	.31	......	.11	
1879	.17	.31	......	.11	
1880	.18	.34	......	.12	
1881	.19	.46	......	.13	
1882	.21	.50	......	.15	
1883	.21	.50	......	.13	
1884	.21	.50	......	.13	
1885	.20	.50	......	.13	
1886	.21	.50	......	.13	
1887	.21	.50	......	.14	
1888	.22	.50	......	.12	
1889	.22	.50	......	.13	
	8 hr. day		8 hr. day	9 hr. day	
1890	.43	.47	$0.28	.14	
1891	.43	.47	.28	.14	
1892	.44	.50	.29	.14	
1893	.43	.50	.30	.14	
1894	.44	.50	.30	.14	
1895	.43	.50	.30	.14	
1896	.44	.50	.30	.14	
1897	.44	.50	.29	.14	
1898	.44	.50	.30	.14	
1899	.45	.55	.33	.14	
1900	.50	.56	.33	.14	
1901	.50	.59	.33	.19	
1902	.51	.65	.36	.17	
1903	.56	.65	.36	.16	
1904					
1905					
1906	......	......	......	......	8 hr. day
1907	.62½	.70	.37½	.22	$0.60
1908	.62½	.70	.37½	.22	.60
1909	.62½	.70	.37½	.22	.60
1910	.62½	.70	.37½	.22	.62½
1911	.62½	.70	.37½	.22	.62½
1912	.62½	.70	.37½	.23	.62½
1913	.62½	.70	......	.22½	.62½
1914	.62½	.75	......	.22½	.62½
1915	.62½	.75	......	.25	.62½
1916	.62½	.75	......	.25	.66
1917	.69	.75	......	.30	.69
1918	.69	.81	......	.40½	.80
1919	.81¼	.87½	.57½	.55	.87½
1920	1.08	1.17	.77½	.75	1.11
1921	1.12½	1.25	.87½	.77	1.12½
1922	1.12½	1.25	.87½	.58	1.12½
1923	1.20	1.42	.95	.61	1.16
1924	1.31¼	1.50	1.00	.68¾	1.25

[I]NDEX STANDARD ESTIMATE FORMS AND SAMPLE ESTIMATES

STANDARD ESTIMATE FORMS 1926 COST CONDITIONS

Common labor	\$0.45 per hour
Teams	0.85 per hour
5-ton trucks	3.00 per hour
1½-ton trucks	1.50 per hour

[E]stimates based on following overhead and profit allowances:

Cost of imported materials plus 6 % for interest and profit.
Cost of freight plus 6 %.
Cost of local materials produced by contractor plus 20 % profit.
Cost of labor plus 20 % profit.
Overhead on labor costs (10 % of pay roll).[1]
Equipment overhead (see Table 224, p. 1261)
Moving plant on job, \$500 to \$1000.

[1] Includes interest on pay roll, insurance, liability, etc.

Grading Equipment
Ordinary road. Earth excavation

Item	Approximate value	Approximate yearly charge including interest, depreciation, repairs, etc.
Keystone grader or steam shovel	$—— to $ 9,000	$—— to $ 3,000
10 to 20 dump wagons or trucks.	$2,000 to 10,000	$1,000 to 5,000
Road scrapers..............	500 to 1,000	200 to 400
Tractors or traction engine......	—— to 5,000	—— to 1,000
Wheel and slush scrapers........	500 to 1,000	200 to 500
Plows, hand tools, etc..........	500 to 1,000	200 to 500
10-ton roller..................	5,000 to 6,000	1,000 to 1,200
Totals....................	$8,500 to $33,000	$2,600 to $11,600

Average amount of work 5 to 8 miles per year, amounting to 15,000 to 100,00 cu. yd. per year.
Approximate equipment overhead charge on excavation from 10 to 20 ct per cu. yd. depending on amount excavated.

ROUGH GRADING ESTIMATES

Heavy Steam-shovel Work (Earth Excavation):

¾-yd. shovel averaging 350 cu. yd. per day.	Per Cubi Yar
Labor, fuel, and water at shovel..............	$0.1
Labor on dump..............	0.
Hauling up to 300′ lead..............	0.
Hauling beyond 300′ lead (1 ct. per Sta.) say..............	0.
Total pay roll..............	0.
Profit..............	0.
Overhead on pay roll 10 %..............	0.
Overhead on equipment (100 days per year)..............	0.
Total estimate..............	$0.

Medium Steam-shovel Work (Earth Excavation):
⅝-yd. shovel averaging 200 cu. yd. per day.

	Per Cub Yar
Labor, fuel, and water at shovel..............	$0.
Labor on dump..............	0.
Hauling up to 300′ lead..............	0.
Hauling beyond 300′ lead (1 ct. per Sta. yard) say..............	0.
Total pay roll..............	$0.
Profit..............	0.
Overhead on pay roll 10 %..............	0.
Overhead on equipment (100 days per year)..............	0.
Total Estimate..............	$0.

Medium and heavy steam-shovel work is commonly bid for 50 to 80 ct per cubic yard, Western New York, 1925.

Light Keystone Grader Work (Earth Excavation):
Average 150 cu. yd. per day.

	Per Cubi Yarc
Labor, fuel, and water at shovel..............	$0.
Labor on dump..............	0.1
Hauling up to 300′ lead..............	0.1
Hauling beyond 300′ lead (1 ct. per Sta. yd.) say..............	0.
Total pay roll..............	$0.4
Profit..............	0.
Overhead 10 % pay roll..............	0.
Overhead on equipment (100 days per year)..............	0.1
Total estimate..............	$0.

Scraper Work (Short Haul):
Reasonable contract price 50 to 70 cts. per cubic yard.

Road Machine Turnpiking:
Reasonable contract price 20 to 40 cts. per cubic yard.

Plow, Hand Shoveling, Team Hauling (500′ lead):

Easy soil (all ordinary conditions)	$1.30 per cubic yard
Hard soil (hard clay and cemented soils)	1.75 per cubic yard

In estimating the price for any road the number of yards of earth to be excavated by the different foregoing methods are estimated roughly, the proper price applied to each class of excavation, and the composite price determined by the total estimate divided by the total yardage.

Rock Excavation

Open cut. Reasonable contract price, Western New York, 1925.

	Per Cubic Yard
Large quantities solid rock	$2.00 to $2.50
Small quantities solid rock	4.00
Large quantities shale or disintegrated solid rock	1.50 to 2.00
Small quantities shale or disintegrated solid rock	3.00

Note.—There is such a wide variation in the cost of roadway rock excavation that any detailed form would be merely misleading.

Trimming Fine Grade for Pavement:
Depends largely on how well road is rough graded. Following cost assumes rough grade correct to within 1″ of finished grade.

	Per Square Yard
Labor cost	$0.06
Profit 20 % of labor	0.012
Overhead 10 % of labor	0.006
Roller overhead	0.002
Total	$0.080

Ordinary bids run from 5 to 10 cts. per square yard.

Trimming Shoulders and Ditches:
Depends largely on completeness of rough grading. Following cost assumes rough grading well done and trimming finished by hand labor including back slopes.

Easy Grading (Ordinary Earth):

	Per Linear Foot of Road
Labor and teams	$0.12
Profit 20 %	0.02
Overhead 10 % of pay roll	0.01
Total	$0.15

Difficult Grading (Small Boulders Mixed with Earth):

	Per Linear Foot of Road
Labor and teams	$0.15
Profit 20 %	0.03
Overhead 10 % of pay roll	0.015
Total	$0.195

Ordinary bids run 10 to 20 cts. per linear foot of road.

Overhaul:
New construction (Bad hauling conditions):

	Per Station Yard
Cost of hauling	$0.008
Profit 20 %	0.002
Overhead	0.001
Total	$0.011

Reconstruction (Excellent hauling conditions):

	Per Statio Yard
Cost of hauling	\$0.004
Profit	0.001
Overhead	0.001
Total	\$0.006

Ordinary bids run from 0.5 to 1.5 cts. per station yard.

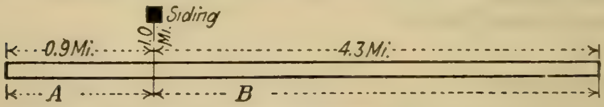
Hauling Schedule of Approximate Cost

	Cents per ton mile	Cents per yarc mile
Teams:		
Hand loading, short hauls out of fields	55	70
Bin loading, average hauls	45	55
Bin loading, long hauls	40	50
Trucks (cost includes overhead charge):		
Hand loading, short hauls less than 1.5 miles	30	40
Bin loading, short hauls	20	25
Bin loading, long hauls over 1.5 mile	16	20

NOTE.—Length of haul is the length for hauling load; that is, if truck loaded, runs 3 miles, dumps, and returns empty, the cost is 3 miles tim cost per mile given in the above schedule.

CALCULATION OF AVERAGE HAUL DISTANCE CASE I

Condition of road uniform. Material to be distributed in proportion to mileage



1st. Method: Assume a shipment of 100 tons.

Tonnage for $A = \frac{0.9}{0.9+4.3} \times 100 = 17$ tons.

Tonnage for $B = \frac{4.3}{0.9+4.3} \times 100 = 83$ tons.

Total ton miles = 286.10
Total tonnage = 100.00

A ..... 17 tons $\times (1.0 + \frac{0.9}{2})$ miles = 24.65 ton miles

B ..... 83 tons $\times (1.0 + \frac{4.3}{2})$ miles = $\underline{261.45}$ ton miles
286.10 ton miles

AVERAGE HAUL
$= \frac{286.10}{100} = 2.86$ miles

2nd. Method: Assume a tonnage of 1 ton per mile.

A ..... 0.9 ton $\times (1.0 + \frac{0.9}{2})$ miles = 1.305 ton miles

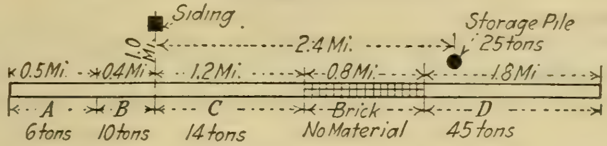
B ..... 4.3 tons $\times (1.0 + \frac{4.3}{2})$ miles = $\underline{13.545}$ ton miles
14.850 ton miles

Total ton miles = 14.85
Total tonnage = 0.9 + 4.3 = 5.2

AVERAGE HAUL
$= \frac{14.85}{5.2} = 2.86$ miles

CALCULATION OF AVERAGE HAUL DISTANCE CASE II

Conditions of road not uniform Proper tonnage for separate stretches of road to be estimated



Assume a shipment of 100 tons

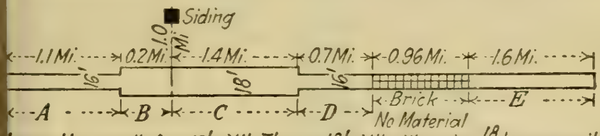
A - 6 tons $\times (1.0 + 0.4 + \frac{0.5}{2})$ miles	= 9.90 ton miles
B - 10 tons $\times (1.0 + \frac{0.4}{2})$ miles	= 12.00 " "
C - 14 tons $\times (1.0 + \frac{1.2}{2})$ miles	= 22.40 " "
D - 45 tons $\times (1.0 + 1.2 + 0.8 + \frac{1.8}{2})$ miles	= 175.50 " "
Storage Pile = 25 tons $\times (1.0 + 2.4)$ miles	85.00 " "
	304.80 " "

Total ton miles = 304.80

Total tonnage = 100.00 AVERAGE HAUL = $\frac{304.80}{100}$ = 3.05 miles

CALCULATION OF AVERAGE HAUL DISTANCE CASE III

ndition of road uniform. Material to be distributed in proportion to area.



ssume 1 ton per mile for a 16' width. Then an 18' width will require $\frac{18}{16}$ tons per mile.

-1.1 ton $\times (1.0 + 0.2 + \frac{1.1}{2})$ miles	= 1.925 ton miles
-$(0.2 \times \frac{18}{16})$ ton $\times (1.0 + \frac{0.2}{2})$ miles	= 0.247 " "
-$(1.4 \times \frac{18}{16})$ ton $\times (1.0 + \frac{1.4}{2})$ miles	= 2.678 " "
- 0.7 ton $\times (1.0 + 1.4 + \frac{0.7}{2})$ miles	= 1.925 " "
-1.6 ton $\times (1.0 + 1.4 + 0.7 + 0.96 + \frac{1.6}{2})$ miles	= 7.776 " "
	14.551

Tonnage for A = $\frac{1.1}{5.20}$ × total shipment
" " B = $\frac{0.2 \times \frac{18}{16}}{5.20}$ × " "
Etc.

otal ton miles = 14.551

otal tonnage = $1.1 + (0.2 \times \frac{18}{16}) + (1.4 \times \frac{18}{16}) + 0.7 + 1.6 = 5.20$

VERAGE HAUL = $\frac{14.551}{5.20}$ = 2.80 miles

PRODUCTION OF CRUSHED STONE
SMALL LOCAL PORTABLE PLANTS

Proportion of Sizes:

For proportion of sizes and weights of crusher outputs, see pages 1173 t[o] 1182.

Cost Estimates

Cost of Quarrying:

Stripping (use earth excavation prices, pp. 1126 to 1127) for amoun[t] required.

Cost of stone per ton.................................... 5 ± ct[s]

Quarrying and delivery to crusher (includes overhead and equipmen[t] charge):

	Per Ton	
Sandstone	$0.40	....
Limestone	0.45	
Conglomerate	0.60	
Trap and granite	0.55	

Crushing (includes overhead charge):

	Per Ton	
Sandstone	$0.25	....
Limestone	0.30	
Conglomerate	0.30	
Trap and granite	0.45	
Subtotal		
Net profit		$0.20
Estimate per ton[1]		

[1] Total output of crusher.

NOTE.—If any part of the total output cannot be used and is wasted, th[e] price per ton for the stone actually used must include cost of waste.

Sample Estimate [Limestone]

Stripping	$0.05
Quarry rights	0.06
Quarrying	0.45
Crushing	0.30
Subtotal	$0.86
Profit	0.20
Estimate	$1.06 per ton
=	1.30 per cubic yard loose measur[e]

[1]Total output of crusher.

Crushing Field-stone Boulders:

1 cu. yd. boulders = 1 cu. yd. crushed stone

1.8 cu. yd. boulders = 1 cu. yd. (1¼ to 3¾″ crushed stone consolidat[ed] measure)

Cost Estimate

	Per Cubi[c] Yar[d]
Cost of field stone	$0.[illegible]
Blasting or sledging per cubic yard actually blasted or sledged	0.[illegible]
Loading to wagons or trucks	0.[illegible]
Hauling to crusher 1 mile	0.[illegible]
Subtotal	.[illegible]
10 % overhead	.[illegible]
Subtotal delivery to crusher	.[illegible]

	Per Cubic Yard	
Crushing (includes overhead charge)		
Sandstone	$0.30	
Limestone	0.35	....
Trap and granite	0.50	
[1] Total per cubic yard (loose measure) screened-out sizes		.....
Profit		$0.25
Estimate per cubic yard loose screened sizes		.....

[1] NOTE.—If any part of the total output cannot be used and is wasted, the rice per cubic yard for the stone actually used must include the cost of the asted product.

SAMPLE ESTIMATE (Limestone)

Cost of stone	$0.15
0.1 cu. yd. sledged	0.06
Loading	0.30
Haul ½ mile	0.35
Subtotal	$0.86
10 % overhead	0.09
	0.95
Crushing	0.35
	$1.30
Profit	0.25
	$1.55 per cubic yard
	$1.20 per ton

PRODUCTION OF SCREENED GRAVEL AND SAND IN SMALL PLANTS

The total cost of output depends on the amount of waste product. In ost pits there is an excess of sand which must be wasted. For weights of reened gravel and proportions of sand and gravel in pits, see page 1182.

COST ESTIMATES

	Per Ton
Stripping [1] (use excavation prices, pp. 1126 to 1127)	$0.05
Excavating and delivery [1] to screening plant	0.25
Screening [1]	0.15
Subtotal	....
Profit	0.15
Estimate per ton total output	....
Price per ton + 30 % ± equals price per cubic yard loose measure	....

[1] Includes overhead.

SAMPLE ESTIMATE

	Per Ton
Stripping	$0.05
Excavating and delivery	0.25
Screening	0.15
Subtotal	0.45
Profit	0.15
Estimate total output of plant	$0.60 per ton screened sizes
	0.80 per cubic yard screened sizes

or 10 % waste estimate = 67 cts. per ton 90 cts. per cubic yard
or 20 % waste estimate = 75 cts. per ton $1 per cubic yard

Washing Sand and Gravel:

Cost of washing varies greatly depending on amount of dirt tc be removed, water supply, etc. It will vary from 15 to 50 cts per ton and no standard estimates can be formulated. Each case is a special problem. Small portable plants are rarely satisfactory and good plant for the production of satisfactory screened anc washed gravel will cost at least from $10,000 to $15,000.

Commercial washing plants in Western New York use about 50c gal. of water per ton of gravel.

STANDARD ESTIMATE FORM FOR BOULDER SUBBASE (FIELD STONE)

Amounts of Material:

A subbase course 6″ deep made of the usual size fence stone requires 1 cu yd. loose for 1 cu. yd. rolled; 12″ depth of finished base requires 1.25 cu. yd loose measure to 1 cu. yd. finished rolled measure.

⅓ cu. yd. gravel or small stone and screenings filler required per cubic yard of finished base course.

Cost Estimate

Cost of cobbles per loose cubic yard..............	$0.20 ±	Multiply these item by 1.25 fo 12″ depth o subbase.
Loading cobbles to wagons by hand per cubic yard.	0.30	
Hauling[1] cobbles 1 cu. yd. loose measure 60 cts. per mile, short hauls 50 cts. per mile long hauls		
Placing cobbles..............................	0.20	
Rolling......................................	0.10	
Filler (see below)		
Total......................................	$....	
20% profit.................................	....	
10% overhead...............................	....	
Estimate...................................	....	

[1] Teams out of fields, bad conditions, short hauls less than 1.5 miles.

Filler:

Cost ⅓ cu. yd. at pit or crusher:......................		
Loading ⅓ cu. yd. (by hand from pile)................	$0.10	...
Loading (from bins)............................	0.01	
Hauling ⅓ cu. yd. per mile........................	0.20	
Spreading ⅓ cu. yd..............................		0.0
Filler total.......................................	$.........	

Sample Estimate

(12″ consolidated depth)

Cost of cobbles, $0.20 × 1.25 cu. yd..............		$0.24
Loading cobbles, 0.30 × 1.25 cu. yd..............		0.38
Hauling 2 miles average ($0.50 × 2 × 1.25).......		1.25
Placing, $0.20 × 1.25 cu. yd.....................		0.24
Rolling, 0.10 × 1.25 cu. yd......................		0.12
Filler:		
Cost ⅓ cu. yd. at pit	$0.10	
Loading.................................	0.10	
Haul 3 miles............................	0.60	
Spreading...............................	0.08	0.88
Total.....................................		$3.11
20% profit................................		0.62
10% overhead..............................		0.32
Estimate..................................		$4.05 per cubic yard

STANDARD ESTIMATE FORM FOR BOULDER BOTTOM COURSE (FIELD STONE)

Same relation of loose and rolled depths as for boulder base. 0.4 cu. yd. gravel or crushed-stone filler required.

Cost Estimate

Cost of cobbles per loose cubic yard	$0.20 ±
Loading to wagons by hand per loose cubic yard	0.30
Hauling[1] at 60 cts. per yard-mile	....
Placing and sledging	0.40
Rolling	0.10
First subtotal	
First subtotal × consolidation (0 for 6″ depth) (0.25 for 12″ depth)	....
Second subtotal	....
Filler (see below)	....
Total	....
20% profit	....
10% overhead	....
Estimate	....
Filler:	
Cost 0.4 cu. yd., loose measure in pit or at crusher	....
Loading 0.4 cu. yd. by hand, 10 cts. / Loading 0.4 cu. yd. from bins, 1 ct.	....
Hauling[1] 0.4 cu. yd. at 20 cts. per mile	....
Spreading and brooming 0.4 cu. yd	0.16
Filler total	....

[1] NOTE.—Hauling by teams out of fields, bad conditions, and short hauls less than 1.5 miles.

Sample Estimate

(12″ consolidated depth)

Cobbles	$0.20 per loose cubic yard
Loading	0.30 per loose cubic yard
Hauling 2 miles	1.00
Placing and sledging	0.40
Rolling	0.10
Subtotal	$2.00 per loose cubic yard
Consolidation 25%	0.50
Subtotal	$2.50 per consolidated cubic yard
Filler:	
Cost 0.4 cu. yd. at pit (gravel)	0.12
Loading	0.12
Haul 3 miles	0.60
Spreading	0.16
Total	$3.50
20% profit	0.70
10% overhead	0.35
Estimate	$4.55 per consolidated cubic yard

GRAVEL FOUNDATION (PIT-RUN GRAVEL)

Gravel foundation courses require 1.2 cu. yd. loose measure per yard consolidated measure.

Cost Estimate

Cost of gravel in pit per loose cubic yard	
Loading gravel by hand 30 cts. per cubic yard; by steam shovel 17 cts. per cubic yard	
Hauling gravel (includes overhead): Teams (short hauls) 0.50 per cubic yard mile; Trucks (hauls less than 1.5 miles) 0.26 per cubic yard mile; Trucks (hauls over 1.5 miles) 0.21 per cubic yard mile	
Spreading gravel 15 cts. per loose cubic yard	$0.15
Loam filler ⅙ cu. yd. if ordered	0.10
Rolling gravel	0.10
Reshaping gravel	0.10
First total per loose cubic yard	
Consolidation 0.2	
Second total per consolidated yard	
20% profit	
10% overhead (pay roll)	
Plant overhead	0.50±
Third total estimate per consolidated cubic yard	

Sample Estimate

Cost gravel in pit	$0.50	per cubic yard (loose)
Loading (steam shovel)	0.17	
Haul (2 miles)	0.40	
Spread	0.15	
Loam filler	0.10	
Rolling	0.10	
Reshaping	0.10	
First total	$1.52	per cubic yard (loose)
Consolidation 0.2	0.30	
Second total	$1.82	per cubic yard (consolidated
20% profit	0.36	
10% overhead	0.18	
Equipment overhead	0.50	
Estimate	$2.86	

SCREENED GRAVEL BOTTOM COURSE

Materials Required:

1 cu. yd. consolidated gravel bottom requires 1.25 cu. yd screened gravel plus 0.35 cu. yd. sand and loam filler.

Cost Estimate

Same as for screened gravel top making due correction fo: amounts of material required (see p. 1139).

LOCAL STONE MACADAM BOTTOM COURSE

Materials Required:

1 cu. yd. of consolidated bottom course requires approximately 1.27 cu. yd loose measure for a 3″ consolidated depth and approximately 1.30 cu. yd loose measure for a 4″ consolidated depth.

The amount of filler required per cubic yard of consolidated bottom is 0.3: cu. yd. of sand or screenings or a mixture of the two depending on how th screenings are utilized. For proportion of sizes in crusher output, se page 1181.

Cost Estimate

For material total, use crushing estimate on page 1130.

Manipulation:

Transfer to trucks or wagons .... $0.01 per cubic yard

Hauling:

Teams	Bad conditions	60 cts. per yard mile	
	Good conditions	50 cts. per yard mile	
Trucks	Short hauls	25 cts. per yard mile	....
	Hauls over 1.5 mile	20 cts. per yard mile	

Spreading:

5⅓ loose depth 15 cts. per cubic yard ⎫
4⅓ loose depth 19 cts. per cubic yard ⎭ ....

Rolling	0.10	
First subtotal	....	per cubic yard
Consolidation 0.27 to 0.30	....	
Second subtotal consolidated stone	....	
Filler (see below)	....	
Total	....	
Labor overhead 10%	....	
Profit 20%	....	
Manipulation total	....	

Screenings (filler):

Cost 0.35 ± cu. yd. in bins	....
Loading to trucks (from bins) $0.005 / Loading to trucks (from piles) 0.12	....
Hauling (use regular hauling rates)	....
Spreading and brooming	0.15
Total cost screening filler	....

Sand Filler:

Cost 0.35 cu. yd. in pit	....
Loading	0.12
Hauling (use regular hauling rates)	....
Spreading and brooming	0.15
Total cost sand filler	....

Note.—If both sand and screenings are used, work out a composite price for the percentage of each kind used.

Summary:

Material total (includes overhead)	....
Manipulation total (includes labor overhead)	....
Equipment overhead (exclusive crushing) (see p. 1261)	$0.60 ±
Estimate per cubic yard consolidated measure	....

Sample Estimate

Filler 50 % screenings; 50 % sand.
Small limestone quarry (total crusher output used. No waste).

Material Estimate:

Quarrying and crushing (see p. 1130)	$1.30 per cubic yard
Consolidation 0.3 %	0.40
Material total	1.70 per cubic yard consolidated

Manipulation:

Transfer to trucks	$0.01 per cubic yard loose
Haul (2 miles) (2 × 20)	0.40 per cubic yard loose
Spread	0.15 per cubic yard loose
Rolling	0.10 per cubic yard loose
First subtotal	$0.66 per cubic yard loose
Consolidation 0.3	0.20
Second subtotal	$0.86 per cubic yard consolidated
Filler (see below)	0.90
Total	$1.76
10 % overhead	0.18
Profit	0.35
Manipulation total	$2.30

Filler	Screenings	Sand
Cost 0.35 cu. yd	$0.44	$0.10
Load	0.01	0.12
Haul 2 miles	0.40	0.40
Spread	0.15	0.15
Totals	$1.00	$0.77

Composite price half sand, half screenings = $0.88—say $0.90.

Summary:

Material consolidated total	$1.70
Manipulation consolidated total	2.30
Equipment overhead	0.60
Estimate	$4.60 per cubic yard consolidated

MACADAM BOTTOM COURSE—IMPORTED MATERIALS

Amount of Material Required:

Total weight crushed limestone (specific gravity 2.7 or 170 lb. per cubic foot solid) according to our records is 3050 lb. per consolidated cubic yard of bottom course 3″ thick and 3150 lb. per cubic yard finished bottom 4″ thick.

Approximately 0.35 cubic yard sand or screenings required for filler.

Cost Estimate

Materials (Limestone):

3″ course 3050 lb. f.o.b. unloading points }	
4″ course 3150 lb. f.o.b. unloading points }	
6 % on material and freight	
Material total	

Manipulation:

Unloading:

Under 2000 tons (shoveling) 35 cts. per ton
Over 2000 tons (elevator) 16 cts. per ton } ....

Hauling:

Teams { Bad conditions 55 cts. per ton mile
Average conditions 50 cts. per ton mile
Good conditions 40 cts. per ton mile
Trucks, short hauls 20 cts. per ton mile
Hauls over 1.5 miles 16 cts. per ton mile } ....

Spreading stone:

5⅓″ loose depth, 12 cts. per ton
4″ loose depth, 16 cts. per ton } ....

Rolling, 08 cts. per ton ....

Filler:

Cost 0.35 cu. yd. at pit or crusher	
Loading 0.35 cu. yd. by hand shoveling	12 cts.
Loading 0.35 cu. yd. from bins	01 ct.
Hauling 0.35 cu. yd. at 7 to 20 cts. per mile (see hauling conditions)	
Spreading and brooming 0.35 cu. yd	15 cts.
Subtotal	
10 % labor overhead	
20 % profit ±	
Manipulation total	

Summary:

Material total	
Manipulation total	
Equipment overhead (see p. 1262)	60 cts. to $1.00
Total estimate per consolidated cubic yard	

Sample Estimate

4″ consolidated depth limestone

Materials:

1.6 tons stone f.o.b. unloading @ $1.15 + $1.00 freight per ton	$3.44
6 % on materials	0.20
Material total	$3.64

Manipulation:

Unloading (1.6 tons × 16 cts.)	$0.26
Hauling 2 miles (2.0 × 1.6 × 16 cts.)	0.51
Spreading (1.6 × 12 cts.)	0.20
Rolling (1.6 × 8 cts.)	0.13

Filler (Sand Pit):

Cost (0.35 cu, yd. × 30 cts.)	0.10
Loading	0.12
Hauling 2 miles (2.0 × 0.35 × 30 cts.)	0.21
Spreading and brooming	0.15
Subtotal	$1.68
10 % overhead	0.17
20 % profit	0.34
Manipulation total	$2.19

Summary:

Material total	$3.64
Manipulation total	2.19
Equipment overhead	0.77
Estimate	$6.60 per consolidated cubic yard

BITUMINOUS CONCRETE BLACK BASE (HOT MIX)

Materials required per ton of finished product generally about 1260 lb. stone, 650 lb. sand, and 90 lb. of asphalt. For weight per consolidated cubic yard, see page 496.

Sample Estimate

Materials (f.o.b. plant switch):

1200 lb. stone at $ 2.15 per ton	$1.29
700 lb. sand at 1.75 per ton	0.61
100 lb. asphalt at 15.00 per ton	0.75
Subtotal	$2.65
6 % on materials and freight	0.15
Material total	$2.80

Manipulation (per ton):

Unload	$0.16
Mixing (labor and fuel)	0.80
Hauling 2 miles (2 × 18 cts. per ton mile)	0.36
Spreading, rolling, and finishing	0.60
Subtotal	$1.92
Labor overhead	0.20
Profit	0.78
Manipulation total	$2.90

Summary:

Material total	$2.80 per ton
Manipulation total	2.90 per ton
Equipment overhead	1.00 per ton
Estimate	$6.70 per ton

CEMENT CONCRETE FOUNDATIONS—IMPORTED MATERIALS

Materials Required (per cubic yard concrete base):

Mix	Cement, barrels	Stone or gravel, cubic yards	Sand, cubic yards
1:3:6	1.1	0.95	0.47
1:2½:5	1.3	0.92	0.46
1:2:4	1.6	0.90	0.45

Allow 10 % waste and excess for net sections for sand and stone.
Steel as ordered.

Typical Estimate

Materials:

.....bbl. cement f.o.b. unloading switch	
.....cu. yd. stone or gravel unloading switch	
.....cu. yd. sand unloading switch	
.....lb. steel	
Subtotal	
10 % waste sand and stone	
6 % on materials and freight	
Material total	

Manipulation:

Unloading:	
......bbl. cement at 8 cts. per barrel	$0.11 ±
1.5 cu. yd. stone and sand at 20 ct	0.30
Hauling:	
......bbl. cement at 3.5 cts. per barrel mile	
1.5 cu. yd. stone and sand at 22 cts. per yard mile	
Mixing, placing, curing:	0.70
Subtotal	
10 % overhead	
Profit	0.70 ±
Manipulation total	

Summary:

Material total	
Manipulation total	
Equipment overhead	$1.00 ±
Estimate per cubic yard	

Sample Estimate

(1: 2½: 5 Mix)

[1] **Materials** (Imported):

1.3 bbl. cement at $2.50 f.o.b. switch	$3.25
0.46 cu. yd. sand at 2.50 f.o.b. switch	1.15
0.92 cu. yd. stone at 2.60 f.o.b. switch	2.40
Subtotal	$6.80
10 % wastage stone and sand	.35
6 % on materials and freight	.45
Material total	$7.60

[1] Note.—Where local materials are used, use local material estimate forms, p. 1130 to 1132.

Manipulation:

Unloading:	
1.3 bbl. cement at 8 cts. per barrel	$0.11
1.5 cu. yd. stone and sand at 20 cts	0.30
Hauling (2 miles):	
1.3 bbl. cement at 3.5 cts. per lbl. mile	0.10
1.5 cu. yd. stone and sand at 21 cts	0.64
Manipulation placing and finishing	0.70
Subtotal	$1.85
10 % labor overhead	0.20
Profit	0.70
Manipulation total	$2.75

Summary:

Material total	$ 7.60
Manipulation total	2.75
Equipment overhead	0.97
Estimate per cubic yard	$11.32

SCREENED GRAVEL TOP COURSE—LOCAL MATERIALS

Materials Required:

1 cu. yd. consolidated measure of finished top course screened gravel requires approximately 1.25 cu. yd. loose screened gravel plus 0.5 cu. yd. sand and loam.

Cost Estimate

Materials (see p. 1131):	
[1] Cost 1.25 cu. yd. screened gravel	
[1] Cost 0.5 cu. yd. sand	
Material total	
Manipulations:	
Loading 1.75 cu. yd. from bins	$0.04
Hauling (use schedule, p. 1128) 1.75 cu. yd	
Spreading gravel 1.25 cu. yd. at 20 cts	0.25
Spreading and brooming sand and loam 0.5 cu. yd	0.25
Rolling	0.12
Reshaping	0.10
Subtotal	
10 % labor overhead	
Profit 20 % =	
Manipulation total	
Summary:	
Material total	
Manipulation total	
Equipment overhead (exclusive screening)	0.50 ±
Estimate per cubic yard consolidated	

[1] Includes overhead and profit.

LOCAL STONE WATER-BOUND MACADAM TOP

Same as for imported top using estimate forms (p. 1130) for production of local material and making due allowance for amount of screenings produced by local crusher. See also sample estimate local stone macadam at the bottom of page 1134.

WATER-BOUND MACADAM TOP COURSE—IMPORTED MATERIALS

Materials Required:

1 cu. yd. consolidated top course requires approximately 3200 lb. of coarse stone and 1250 lb. of screenings where limestone is used (sp. gr. 2.7 or 170 lb. per cubic foot solid rock). See page 442 for weights of different rocks of different sizes.

Cost Estimate

Materials:	
4450 lb. limestone f.o.b. unloading point	
6 % on stone and freight	
Materials total	
Manipulation:	
Unloading from cars at 16 cts. per ton	
Hauling (regular schedule p. 1128)	
Spreading stone at 18 cts. per ton	
Spreading screenings at 30 cts. per ton (hand)	
Spreading screenings at 10 cts. per ton (mechanical)	
Rolling at 05 cts. per ton	
Puddling at 08 cts. per ton	
Subtotal	
10 % overhead	
20 % profit ±	
Total manipulation	
Summary:	
Material total	
Manipulation total	
Equipment overhead	60 cts. to $1.00
Estimate per consolidated cubic yard	

Sample Estimate

Materials:

2.22 tons limestone at \$2.25 per ton f.o.b. switch	\$5.00
6 % on materials	0.30
Materials total	\$5.30

Manipulation:

Unloading 2.22 × 16 cts	\$0.36
Hauling 2 miles (2.22 × 2.0 × 16 cts.)	0.71
Spreading stone 1.6 tons × 18 cts	0.29
Spreading screenings 0.62 tons × 20 cts	0.12
Rolling 2.22 tons × 5 cts	0.11
Puddling 2.22 tons × 8 cts	0.18
Subtotal	\$1.77
10 % overhead	0.18
Profit 20 % ±	0.36
Manipulation total	\$2.31

Summary:

Material total	\$5.30	
Manipulation total	2.31	
Equipment overhead	0.69	
Estimate	\$8.30	per cubic yard

LOCAL STONE BITUMINOUS MACADAM TOP

Same as for imported bituminous macadam using estimate (see p. 1130) for production of local material. See also local stone macadam, sample estimate, page 1134.

BITUMINOUS MACADAM TOP—IMPORTED MATERIALS

Amounts of Material Required:

Stone:

Total weight of limestone (sp. gr. 2.7 or 170 lb. per cubic foot solid) according to our best records is 4250 lb. per cubic yard of finished bituminous macadam 2½″ consolidated depth and 4350 lb. per cubic yard of 3″ consolidated depth. The percentage of different sizes are as follows.

1½ to 2½″ size crushed stone 65 to 75 % of total.
¾ to 1½″ size crushed stone 20 to 15 % of total.
Dustless screenings 15 to 10 % of total.

Bitumen:

1.5 to 1.75 gal. single coat per square yard.
2.0 to 2.25 gal. double coat per square yard.
Single coat recommended on steep grades.

Cost of Manipulation:

Overhead charge (interest, depreciation, repairs, bonds, etc.).

Short jobs (1½ miles or less, eliminations) \$1.00 per consolidated cubic yard.

Long jobs (ordinary contracts) ....\$0.60 per consolidated cubic yard.

Interest on Cost of Materials and Freight 6 %.

Profit:

Allow enough to give 15 % net profit for job over and above overhead and interest charge.

Unit prices based on:

Labor 50 cts. per hour.
Teams 90 cts. per hour.
5-ton trucks \$3.00 per hour.
1½-ton trucks \$1.50 per hour.

Unloading Stone:

Small jobs 2.2 tons at 35 cts. per ton.
Large contracts 2.2 tons at 16 cts. per ton.

Hauling:

Teams	Bad conditions	2.2 tons at 55 cts. per ton mile
	Average conditions	2.2 tons at 50 cts. per ton mile
	Good conditions	2.2 tons at 40 cts. per ton mile
Trucks	Short haul, 20 cts. per ton mile	
	Long haul (over 1.5 miles) 16 to 18 cts. per ton mile.	

Spreading Stone:

No. 3 stone 1.5 tons at 18 cts. per ton.
Screenings and
No. 2 stone 0.7 tons at 70 cts. per ton.

Rolling:

2.2 tons at 12 cts. per ton.

Heating and Spreading Bitumen.

Small jobs 2.25 gal. at 5 cts. per gallon.
Long jobs 2.25 gal. at 3 cts. per gal.

Hauling Bitumen:

0.1 ct. per gallon per mile.

BITUMINOUS MACADAM TOP—IMPORTED MATERIALS SHORT JOBS ELIMINATIONS

Sample Estimate

Materials:

2.2 tons f.o.b. delivery point $1.15 + $1.00 per ton freight	$4.73
27 gallons bitumen f.o.b. delivery point at 10 cts. per gallon	2.70
6 % on materials and freight	0.45
Materials total	$7.88

Manipulation:

Unloading stone (2.2 tons) at 35 cts. per ton	$0.77
Hauling stone 2.2 tons 2 miles at 16 cts. per ton mile	0.70
Spreading:	
1.5 tons No. 3 stone at 18 cts. per ton	0.27
0.7 tons screenings No. 2 at 70 cts. per ton	0.50
Rolling 2.2 tons at 12 cts. per ton	0.26
Hauling bitumen 27 gal. at 0.1 ct. per gallon mile	1.35
Heating and spreading bitumen 27 gal. at 0.05 cts	1.35
Manipulation total	$3.90

Summary:

Material total	$ 7.88
Manipulation total	3.90
Overhead	1.00
Net profit	0.80
Total	$13.58 per cubic yard in place.

Say $13.60 per cubic yard including bitumen or $1.15 per square yard.
Long contracts run about $1 to $1.10 per square yard 3″ consolidated depth.

BITUMINOUS CONCRETE SURFACE—HOT MIX

Materials Required:

The amount of materials will vary considerably depending on the source of supply (see Design of Bituminous Concretes p. 495). For weight per consolidated cubic yard see page 496.

Cost Estimate (Per Ton)

Materials (f.o.b. plant switch):	
Stone	
Sand	
Dust (filler)	
Asphalt	
Subtotal	
6 % on materials and freight	
Material total per ton	
Manipulation (Per ton):	
Unloading	$0.16
Mixing (labor and fuel)	1.00
Hauling at 18 cts. per ton mile	
Spreading (labor)	0.60
Rolling and finishing (labor and fuel)	0.20
Subtotal	
10 % overhead	
Profit	$1.00±
Manipulation total	
Summary:	
Material total	
Manipulation total	
Plant overhead, etc.	$0.80 to $2.00 (see p. 1264)
Estimate per ton	

TOPEKA TOP COURSE—IMPORTED MATERIALS

Sample Estimate

Materials (Per ton finished pavement):	
500 lb. stone at $ 2.15 per ton (f.o.b. plant)	$0.54
1160 lb. sand at 1.75 per ton (f.o.b. plant)	1.02
170 lb. dust at 6.00 per ton (f.o.b. plant)	0.51
170 lb. asphalt at 15.00 per ton (f.o.b. plant)	1.28
	$3.35
6 % on material and freight	0.20
Material total	$3.55
Manipulation (Per ton finished pavement):	
Unloading	$0.16
Mixing	1.00
Hauling 2 miles	0.40
Spreading	0.60
Rolling and finishing	0.20
Subtotal	$2.36
Overhead labor	0.24
Profit	$1.00
Manipulation total	$3.60
Summary:	
Material total	$3.55
Manipulation total	3.60
Equipment overhead	1.05
Estimate per ton	$8 20

SHEET ASPHALT SURFACING

Cost data from city pavements by Besson

Recapitulation of Cost.—For a surface 1½" in thickness, sheet asphalt pavement costs may be tabulated as follows; that for materials, of course, depending greatly upon local conditions, while the other costs should fluctuate to a much less degree.

Sand at $0.80 ton, 120 lb. =	$0.048 per sq. yd.		
Dust at $5.00 ton, 30 lb. =	0.075		
Asphalt at $15.00 ton, 15 lb. =	0.113		
Total for materials		$0.236	
Plant charges at 100 days per year	0.075		
Labor at the plant	0.090		
Fuel	0.030		
Total at the plant		0.195	
Transportation at $9 per ton		0.075	
Spreading the mixture		0.045	
Surface finishing		0.015	
Total for operating			$0.566
10% foreman and overhead			0.057
10% contingencies			0.057
15% contractor's profit			0.085
Estimated bid price per sq. yd.			$0.77

CEMENT-CONCRETE PAVEMENT—IMPORTED MATERIALS

Typical Equipment—Pavement Proper

Item	Approximate value	Approximate yearly charge including interest, depreciation, repairs, storage, taxes, etc. Minimum	Maximum
Clam shovel or elevator unloader	$ 2,000 to $ 8,000	$ 600	$ 2,400
Bin and batcher	1,000 to 3,000	300	900
10 to 20 Ford trucks or smaller number of large trucks	5,000 to 10,000	3,500[1]	7,000
Six- to seven-bag batch concrete mixer	6,000 to 7,000	3,000	3,500
3,000 lin. ft. steel forms	2,000 to 3,000	1,600	2,400
Small tools for mixing, placing, and finishing	200 to 300	200	300
25,000'± water pipe line	4,000 to 6,000	2,000	3,000
Pumping equipment	800 to 1,500	200	500
First totals	$21,000 to $38,000	$11,400	$20,000
Second totals exclusive trucks	16,000 to 31,000	8,000	13,000
Moving plant and installing on job	....	$ 500	$ 1,000

Average yearly output 5 to 8 miles of road = 10,000 to 20,000 cu. yd. per year.

First total	$12,000 to $21,000
Second total	$ 8,500 to $14,000
Approximate average overhead on equipment per cubic yard of pavement	$1.00 to $1.50
Approximate[1] average overhead exclusive of haulage which is often sublet	$0.70 to $1.20

[1] Note.—Haulage is often sublet or trucks hired by the day which becomes pay-roll charge.

Materials Estimate per Cubic Yard of Pavement:

Cement:

1:1½:3 mix....	1.9 bbl.	at ..... per bbl. .... f.o.b. unloading point, bags returned.
1:2 :3 mix....	1.7 bbl.	
1:2 :4 mix....	1.6 bbl.	

Sand (Loose measure):[1]

1:1½:3 mix....	0.42 cu. yd.	at ..... per cubic yard .... f.o.b. unloading point
1:2 :3 mix....	0.52 cu. yd.	
1:2 :4 mix....	0.45 cu. yd.	

Crushed Stone or Screened Gravel (Loose measure):[1]

1:1½:3 mix....	0.85 cu. yd.	at ..... per cubic yard .... f.o.b. unloading point
1:2 :3 mix....	0.77 cu. yd.	
1:2 :4 mix....	0.90 cu. yd.	

Expansion Joints $0.10

Steel Reinforcement: ... to ... lb. per cubic yard concrete f.o.b. unloading point.......................................

Total...

Allow 10 % for wastage and excess of actual quantities over net section...

Allow 6 % for demurrage, interest, and profit on materials......

Material estimate total...........................

[1] NOTE.—Sand and stone is usually sold by the ton and the weights will vary considerably for different sources of supply, sizes ordered, and whether sand is washed or taken directly from pit. The weight per cubic yard loose measure as shipped must be determined for each separate case (see pp. 1180 and 1182).

Labor and Fuel Costs (per cubic yard concrete):

Unloading and batching:

Cement:

70% direct car to trucks 5 cts. per bbl.

30% storage and rehandling 15 cts. per bbl.

1:1½:3 mix......................	2 bbl. at 8 cts.	= $0.16–
1:2 :3 mix......................	1.8 bbl. at 8 cts.	
1:2 :4 mix......................	1.7 bbl. at 8 cts.	

Sand and Coarse Aggregate:

1.5 cu. yd. at 20 cts. per cubic yard (loose measure)....... $0.30 ±

Steel reinforcement —— lb. at .02 ct. per pound..............

Hauling (Trucks including depreciation, repair, etc.):

Cement:

1.7 to 2.0 bbl. at 3.5 cts. per barrel mile.......................

Sand and Stone:

1.5 cu. yd. at 21 cts. per cubic yard mile over 1.5 miles; 26 cts. per cubic yard mile under 1.5 miles ....

Steel:

—— to —— lb. at 0.02 ct. per pound mile........................

Manipulation:

Forms..................	per cubic yard pavement	$0.12	...... $0.85
Mixing.................	per cubic yard pavement	0.11	
Placing concrete........	per cubic yard pavement	0.15	
Placing steel and joints.	per cubic yard pavement	0.045	
Finishing steel and joints	per cubic yard pavement	0.105	
Cover and curing.......	per cubic yard pavement	0.25	
Water supply..........	per cubic yard pavement	0.07	

Total...

10% overhead...................................

Profit.................................. $1.00 to $1.50

Pay roll total estimate.............................

Summary:

Pay roll total.........................

Material total.........................

Equipment total (exclusive hauling)... $1.00 ±

Estimate......................... per cubic yard pavement

Sample Estimate

(7½″ – 6½″ – 7½″) (1: 1½: 3 mix) (Imported materials)
Large job 10 miles in length.

Materials (Imported):[1]

1.9 bbl. cement f.o.b. switch at $2.50 per bbl.	$4.75
0.42 cu. yd. sand f.o.b. switch at $2.50 per cubic yard	1.05
0.85 cu. yd. stone f.o.b. switch at $2.60 per cubic yard	2.20
Expansion joints per cubic yard pavement	0.10
25-lb. steel per cubic yard pavement at 3 cts	0.75
Total	$8.85
10% wastage	0.30
6% on materials	0.60
Materials total	$9.75

[1] NOTE.—Where local materials are used, use material estimate forms, pp. 1130 to 1132

Manipulation:

Unloading:	
Cement	$0.16
Sand and stone	0.30
Steel	0.01
Hauling (2 miles):	
Cement 2 × 1.9 × 3.5 cts	$0.14
Sand and stone 2 × 1.5 × 21 cts	0.63
Steel 25 × 0.02 ct	0.01
Mixing, placing, curing, etc.	0.85
Subtotal	$2.10
Profit	1.00
10% overhead	0.21
Pay roll total	$3.31

Summary:

Pay roll total	$ 3.31
Material total	9.75
Equipment overhead	1.04

Estimate.... $14.10 per cubic yard = $2.75 per square yard 7″ depth.

BRICK SURFACING

Materials Required:

Brick: 40 per sq. yd. usual standard (3½″ by 4″ by 9″).
Sand cushion (1″ thick): 0.028 cu. yd. per square yard.
Cement grout (1 to 1): 0.03 bbl. cement 0.05 cu. yd. sand per square yard.
Sand cover (1″ thick): 0.028 cu. yd. per square yard.

Amount of Cement and Sand Different Mortars (per Cubic Yard Mortar)

1:1 mix	4.8 bbl. cement	0.77 cu. yd. sand
1:1½ mix	3.88 bbl. cement	0.86 cu. yd. sand
1:2 mix	3.20 bbl. cement	0.95 cu. yd. sand
1:3 mix	2.40 bbl. cement	1.07 cu. yd. sand
1:4 mix	1.90 bbl. cement	1.12 cu. yd. sand

For typical estimates, see below and page 1214.

Cost Data from City Pavements

By Besson

Cost Data.—Typical data (1922) for the cost of a brick surface per square yard are as follows:

	Per Square Yard
36 bricks at $50 per thousand (3″ depth)	$1.80
Handling to trucks	0.02
Hauling	0.20
Piling on street	0.02
Laying and rolling	0.10
Bituminous filler (plus 10 to 15 cts. if poured)	0.18
Sand cushion (plus 10 cts. if cement is added)	0.08
	$2.40
15% contingencies and overhead	0.36
15% profit	0.36
Estimate	$3.12

Cost Data from City Pavements

By Besson

Stone Block Surfacing

Cost Data.—Typical data (1922) for the cost of a granite-block surface are:

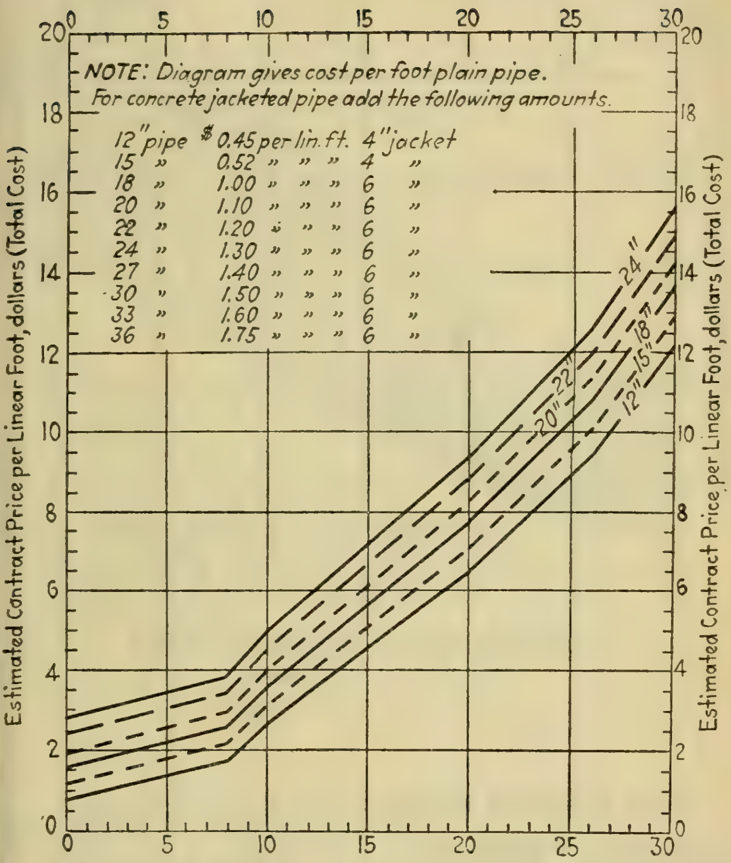
	Per Square Yard
30 blocks at $120 per thousand	$3.60
Handling to trucks	0.03
Hauling	0.32
Piling on street	0.02
Laying and ramming	0.30
Mastic filler	0.30
Sand cushion (plus 25 cts. if cement is added)	0.13
	$4.60
Contingencies and overhead	0.50
Profit	0.70
Total estimate	$5.80

SAMPLE ESTIMATE FORM FOR PIPE CULVERTS WESTERN NEW YORK

Size and kind	Approximate price per foot[1] f.o.b. unloading point	Approximate costs per foot of length				
		Unloading	Hauling per mile	Installation not including trenching	Joints	Average bid price, Western New York, 1926
Light-weight standard water pipe ($50 per ton):						
12″ cast iron	2.00	0.07	0.01	0.09	0.02	$3.00
14″ cast iron	2.50	0.07	0.01	0.09	0.03	3.50
16″ cast iron	3.00	0.08	0.02	0.10	0.03	4.00
18″ cast iron	3.75	0.12	0.03	0.15	0.04	5.00
Lock-joint cast-iron culvert pipe:						
12″	2.45	0.03	0.01	0.06	0.02	3.50
14″	2.65	0.04	0.01	0.06	0.03	3.70
16″	3.26	0.05	0.01	0.07	0.03	4.00
18″	3.67	0.06	0.015	0.09	0.04	5.00
24″	6.52	0.08	0.02	0.12	0.06	7.50
Corrugated metal						
12″	1.20	0.03	0.01	0.03	....	1.60
14″ } 15″	....	0.03	0.01	0.03	....	....
16″ } 15″	1.60	0.03	0.015	0.03	....	2.00
18″	1.90	0.04	0.02	0.04	....	2.50
24″	2.80	0.05	0.02	0.05	....	3.50
Reinforced concrete:						
12″	0.90	0.02	0.01	0.06	0.02	1.70
15″	1.10	0.03	0.01	0.06	0.03	2.00
18″	1.40	0.04	0.02	0.07	0.04	2.30
24″	2.20	0.06	0.02	0.08	0.06	3.50
Double-strength[2] vitrified pipe:						
12″	0.70	0.02	0.01	0.06	0.02	0.90
15″	0.90	0.03	0.01	0.06	0.03	1.30
18″	1.40	0.04	0.02	0.07	0.04	1.60
24″	2.40	0.06	0.02	0.08	0.06	3.00

[1] Prices for pipe are for car load lots.

[2] Where vitrified pipe is used it is generally jacketed with concrete th cost of which must be added to the figures given in the tabulation. Fo weights and dimensions of culvert pipe, see Chap. XIV, pp. 1079 to 1084.



Average cost sewers. (Lima, Ohio, 1921.)

FIG. 325.

Average cost sewers. (Lima, Ohio, 1921.)
FIG. 325.—(*Continued.*)

COST ESTIMATE FORMS—BRIDGE AND CULVERTS

Earth Excavation (Foundations):

Dry-earth hand work	$2.50 per cubic yard
Wet-earth hand work	3.50 per cubic yard
Dry-earth steam shovel	0.80 per cubic yard
Dry-earth slip scrapper	0.60 per cubic yard

Rock Excavation:

Removing old masonry	4.00 per cubic yard
Rock in foundations	5.00 to 6.00 per cubic yar
Shale in foundations	4.00 per cubic yard

Cofferdams or Flumes:
$80 per M ft. b.m. in place required for protection.

Timber Piles:
$1.00 per foot for driving (small jobs).
0.50 per foot for driving (large jobs).
0.40 per foot delivered at bridge.

Bar Steel: Use 6 cts. per pound in place except for thin reinforced side wa culverts in which case use 8 cts. per pound.

Rolled Beams (Usual bid 6 cts. per pound):

Cost f.o.b. switch	$0.032 per pound
Unload to trucks	0.001
Hauling per mile	0.001 per pound
Erecting	0.005 per pound
Total	$0.039
10 % overhead	0.005
Profit	0.008
Total	$0.052

NOTE.—Add $0.001 per mile for each mile over first mile.

Structural Steel (In place):

Usual estimate { 7 cts. per pound plate girders. / 7.5 cts. per pound trusses.

Dismantling steel superstructure	$10.00 per ton
Repointing old masonary	0.05 per sq. ft.

Cement: Allow 30 cts. per barrel net profit.

Cost per barrel f.o.b. unloading switch	$2.44
Unload to trucks	0.08
Haul at 3.5 cts. per mile per barrel	0.04
Incorporating in mix (included in concrete manipulation)	0.00
Total	$2.56
5 % overhead	0.14
Profit	0.30
Estimate per barrel for 1-mile haul	$3.00

Add 3.5 cts. for each mile over 1-mile haul.

COST ESTIMATE FORMS—CONCRETE CULVERTS AND BRIDGES

Profit:

Allow $2 per cubic yard net profit over and above all costs including equipment, overhead bonds, liability, etc.

Materials (10 % wastage allowed on sand and stone):

1: 2½: 5 abutment concrete:
- 0.5 cu. yd. (0.75 ton) sand f.o.b. switch } ....
- 1.0 cu. yd. (1.2 tons) stone f.o.b. switch }

1:2:4 culvert concrete:
- 0.48 cu. yd. (0.73 ton) sand f.o.b. switch } ....
- 0.95 cu. yd. (1.14 tons) stone f.o.b. switch }

1:2:3½ concrete:
- 0.52 cu. yd. (0.77 ton) sand } ....
- 0.92 cu. yd. (1.1 tons) stone }

Total ....

6 % overhead ....

Material total ....

Manipulation (per cubic yard concrete):

Unload (1.5 cu. yd. sand and stone):

By hand (small jobs)	60 cts. per cubic yard	$0.90
By machinery (large jobs)	20 cts. per cubic yard	0.30 ±

Hauling (1.5 cu. yd.):
- Hand loading less than 1.5 miles at 40 cts. per yard mile
- Bin loading less than 1.5 miles at 25 cts. per yard mile
- Bin loading hauls over 1.5 miles at 20 cts. per yard mile

Forms:	Per Cubic Yard
Small culverts 5′ span or less	$ 3.00
BR 101 standard culverts	4.00
701 abutments	2.50
703 abutments	2.00
Slab decks	6.00
T-beam decks	8.00
Jack-arch decks (corrugated metal)	5.00
Trestles (25 height)	13.00
Parapets (fancy)	10.00
Reinforced-concrete arch rings	10.00

	Per Cubic Yard
Mixing and Placing:	
Culverts (standard)	$ 2.00
Abutments	1.50
Superstructures slab	2.00
Superstructures T and Jack arch	2.50
Parapets	3.00
BR 101 culverts	2.50
Rub Finish:	
Abutments and wings	$ 0.30
Parapets and copings (fancy)	3.00
Total	
10% overhead	
Manipulation total	

CONCRETE SUMMARY

	Per Cubic Yard
Material total	
Manipulation total	
Equipment overhead	$1.00
Profit	2.00
Total estimate	

CONDENSED SCHEDULE OF CULVERT AND BRIDGE CONCRETE PRICES DIVISION 4, WESTERN NEW YORK, 1926

(Compiled by W. G. Harger from Cost Data Collected in 1926)

General Basis of Costs:

0.75 ton sand per cubic yard concrete.
1.15 tons stone or gravel per cubic yard, concrete.
Cost of sand and stone per cubic yard concrete, $3.60 f.o.b. unloading point
Unloading by hand shoveling from cars.
Average haul 4 miles switch to work.

NOTE.—To correct for other conditions of cost, proceed as follows:

Correct prices directly for difference in cost of materials f.o.b. switch unloading point.

If stone and sand and unloaded mechanically, reduce prices of concrete 60 cts. per cubic yard.

If haul is not 4 miles, either add or subtract 35 cts. for each mile over or under the 4 miles estimated.

Typical Unit Costs of Concrete (4-mile haul)

(Cement and reinforcement not included)

	Per Cubic Yard
Standard culverts (under 5′ span) Fig. 65, page 221	$15.00
BR 101 culverts (6 to 10′ span) Fig. 67, p. 224	17.00
Abutment and wings (Br 701 to 703) Fig. 69*B*, page 241	13.50
Slab floor concrete (Br 201) Fig. 69*A*, page 237	18.00
Jack-arch floor concrete (Br 301) Fig. 76*A*, page 276	18.00
T-beam floor concrete (Br 401) Fig. 73*A*, page 252	21.50
Parapet concrete (Br 201, 301, and 401) Fig. 73*A*, page 252	27.00
Reinforced-concrete arch rings Fig. 71*A*, page 249	23.50
Trestle concrete-railway crossing designs, approximately	28.50

Typical Cost Estimates

Small jobs assuming material unloaded by hand before regular unloading equipment is installed.

Culverts (Less than 5′ span) (mass concrete)
1:2:4 mix):
Sand $1.70 per ton f.o.b. switch.
Stone $2.10 per ton f.o.b. switch.

Materials:

0.73 tons sand at $1.70	$1.24
1.14 tons stone at $2.10	2.40
Total	$3.64
6 %	0.22
Materia total	$3.86

Manipulation:

Unload by hand 1.43 cu. yd. at 60 cts	$0.86
Haul 1.43 cu. yd. 4 miles at 25 cts. per mile	1.43
Forms	3.00
Mixing and placing	2.00
Rub finish	0.30
Total	$7.59
Exclusive of hauling 10% overhead	0.62
Manipulation total	$8.21

NOTE.—Add or subtract 35 cts. for every mile over or less than 4 miles as hown.

ummary:

Material total	$ 3.86
Manipulation total	8.21
Equipment overhead	1.00
Profit	2.00

$15.07, say $15, does not include cement or reinforcement.

ulverts (BR 101 standard 6 to 10′ span reinforced side walls and bottom):
1:2:3½ mix):
Sand $1.70 per ton f.o.b. switch.
Stone $2.10 per ton f.o.b. switch.

laterials:

0.77 ton sand at $1.70	$1.32
1.1 tons stone at $2.10	2.32
Total	$3.64
6 %	0.22
Material total	$3.86

Ianipulation:

Unload 1.44 cu. yd. stone and sand at 60 cts	$0.86
Haul 1.44 cu. yd. 4 miles at 25 cts. per mile	1.43
Forms	4.00
Mixing and placing	2.50
Rub finish	0.30
	$9.09
Exclusive of hauling 10 % overhead	0.77
Manipulation total	$9.86

NOTE.—Add or subtract 35 cts. for every mile over or under a 4-mile haul

ummary:

Material total	$ 3.86
Manipulation	9.86
Equipment overhead	1.00
Profit	2.00

$16.72, say $17, does not include cement or reinforcement.

butment Costs (BR 701–703) see Fig. 69*B*, page 241.
1: 2½: 5 mix:
Sand $1.70 per ton f.o.b. switch.
Stone $2.10 per ton f.o.b. switch.

Materials:

0.75 ton sand at $1.70	$1.27
1.2 tons stone at $2.10	2.52
Total	$3.79
6 %	0.23
Material total	$4.02

Manipulation:

Unload by hand 1.43 cu. yd. at 60 cts.	$0.86
Haul 1.5 cu. yd. 4 miles at 25 cts. per yard mile	1.50
Forms	2.00
Mixing and placing	1.50
Rub finish	0.30
	$6.16
Exclusive of hauling 10% overhead	0.47
Manipulation total	$6.63

NOTE.—Add or subtract 37 cts. per mile for each mile of haul over or unde 4 miles.

Summary:

Materials	$ 4.02
Manipulation	6.63
Equipment overhead	1.00
Profit	2.00
	$13.65, say $13.50 per cubic yard, does no include cement or reinforcement

Slab Deck Concrete (BR 201) and **Jack-arch Deck Concrete** (BR 302) Fig 76*A*, page 276:

1: 2: 3½ mix:

Sand $1.70 per ton f.o.b. switch.

Stone $2.10 per ton f.o.b. switch.

Materials:

0.77 ton sand at $1.70	$ 1.3
1.1 tons stone at $2.10	2.3
Total	$ 3.6
6 %	0.2
Material total	$ 3.8

Manipulation:

Unload by hand 1.44 cu. yd.	$ 0.8
Haul 1.44 cu. yd. 4 miles	1.4
Forms	6.0
Mixing and placing	2.0
	$10.2
Exclusive of hauling 10% overhead	0.8
Manipulation total	$11.1

NOTE.—Add or subtract 35 cts. for each mile hauled over or under 4 miles

Summary:

Material total	$ 3.86
Manipulation total	11.17
Equipment overhead	1.00
Profit	2.00
	$18.03, say $18, exclusive of cement an reinforcement.

T-beam Superstructures (BR 401) and **Reinforced-concrete Arches**:

1: 2: 3½ mix:

Sand $1.70 per ton f.o.b. switch.

Stone $2.10 per ton f.o.b. switch.

Materials:

0.77 ton sand at $1.70	$ 1.32
1.1 tons stone at $2.10	2.32
Total	$ 3.64
6%	0.22
Material total	$ 3.86

Manipulation:

Unload by hand 1.44 cu. yd.	$ 0.86
Haul 1.44 cu. yd. 4 miles	1.43
Forms (T-beam construction)	8.00
Mixing and placing	2.50
Finishing	0.50
Total	$13.29
Overhead 10% exclusive of hauling	1.18
Manipulation total	$14.47

NOTE.—Add or subtract 35 cts. for each mile hauled over or under 4 miles s estimated.

ummary:

Materials	$ 3.86
Manipulation	14.47
Equipment	1.00
Profit	2.00
	$21.33 T-beam.
	23.50 arch rings.

arapet Concrete (BR 201, 302, and 401):

1: 2: 3½ mix:

Sand $1.70 per ton f.o.b. switch.
Stone $2.10 per ton f.o.b. switch.

aterials:

0.77 ton at $1.70	$ 1.32
1.1 tons at $2.10	2.32
	$ 3.64
6%	0.22
Materials	$ 3.84

anipulation:

Unload	$ 0.86
Haul 4 miles	1.43
Forms	10.00
Placing	3.00
Finishing	3.00
	$18.29
Labor overhead	1.68
Manipulation	$19.97

NOTE.—Add or subtract 35 cts. per mile over or less than the 4 miles timated.

ummary:

Materials	$ 3.84
Manipulation	19.97
Equipment	1.00
Profit	2.00
	$26.81, say $27.

Incidental Items.—Incidental minor item prices should be com led for the locality in question and the specifications and desig ed locally. The following list is for items in Western New York 926):

SAMPLE COST ESTIMATES

Incidental Items (see also Chap. XII, p. 768):

Clearing and Grubbing:	
Sage brush	$ 20 to $ 60 per acre
Small trees and brush	100 to 150 per acre
Large trees, heavy growth	300 to 500 per acre
Pipe underdrain (exclusive excavation and porous filling):	
4" vitrified pipe	$0.25 per linear foot
6" vitrified pipe	0.35 per linear foot
Relaying old pipe	0.20 per linear foot
Manholes	10.00 per foot height
Manhole covers	0.10 per pound
Pipes, all kinds (see p. 1148).	
Curbing:	
6" medium sandstone	$2.10 per foot
Concrete curb, includes cement	25 per cubic yard
Resetting old curb	1.00 per foot
Curb bar for concrete curb	0.30 per foot
Gutters:	
Cobble, cement joints	$ 1.25 per square yard
Concrete, includes cement	18 per cubic yard
Guard rail:	
Wooden	$ 0.75 per linear foot
Resetting old rail	0.50 per linear foot
Steel cable, concrete posts	1.50 per linear foot
Concrete guide posts set 6' to 8' centers (Cost at plant $1.60)	3.00 each, $0.50 per lin. ft.
2" pipe rail	$ 3.00 per linear foot
Scarifying and reshaping macadam	0.10 per square yard
Maintaining traffic	0.20 per linear foot
Timber and lumber in place	80 per M ft. b.m.
Rip-rap	2.00 to 4.00 per cubic yard
Grouted rip-rap	7.00 per cubic yard exclusive c cement
Repointing masonry	$ 0.05 per sq. ft.
Refinishing old concrete	0.15 per sq. ft.
Repair disintegrated concrete	0.50 per sq. ft.
Gunite refinish	0.30 to 80

Land Damage Costs.—It is desirable to establish schedules of reasonabl values for locality in question and to use these schedules in making initia offers. If property owner is not reasonable, condemnation should be resorte to.

Land acquired, twice prevailing acreage value.

Fruit trees, twice capitalized value from average crop, or loss from tim required to plant and grow other trees.

Moving houses, one and one-half times cost of moving to suitable locatio

Western New York Approximate Schedules (Condemnation

Poor gully land	$ 50 per acre
Ordinary farm land	150 per acre
Vineyards	500 per acre
Orchards	700 per acre
Moving houses	1000 each

DETAIL COST DATA AND AMOUNTS OF MATERIAL

Cost of Earth Excavation.—Table 211 shows the cost of earth work on four roads in New York State which represent easy average, and difficult work. The cost per cubic yard include excavation, placing in fill, fine grading for pavement, and trimmin shoulders and ditches. For heavy fills with short hauls, whee scrapers were used but the largest part of the work was done b team plowing, hand shovelling and wagon haul.

Table 212 shows the cost of steam-shovel rough grading includin excavation, haul, placing, and compacting. This job was no particularly well handled and is somewhat more costly than well managed work.

TABLE 211.—EARTH EXCAVATION

Road No.	Length, Miles	Total Excavation Cu. Yds.	Wages per Hour		Cost per Cu. Yd.	Kind of Soil	Engineer
			Men	Teams			
1	2.5	8,600	$0.175	$0.45	$0.452	Loam and gravel, easy work	E. E. Kidder
2	5.5	28,000	0.175	0.45	0.484	Largely clay, hard excavation	S. O. Steere
3	6.0	18,000	0.15	0.45	0.46	Gravel, sand, clay, loam, etc., average work	W. G. Harger
4	4.0	10,000	0.175	0.40	0.65	25% of excavation, small boulders, unusually hard excavation	W. G. Harger

TABLE 212.—STEAM-SHOVEL EXCAVATION—CLAY SOIL (HEAVY CUT)

	1924			1925									
	Days worked per month										Total man days	Rate	
	Oct.	Nov.	Dec.	May	June	July	Aug.	Sept.	Oct.	Nov.			
Superintendent	..	....	..	12	26	26	26	17	7	11½	125½	$ 8.00	$1,004.00
Engineer	..	15	13	12	26	26	46	11	8	12½	169½	9.25	1,567.67
Fireman	..	15	13	12	25	24	44	10	8	12½	163½	5.00	817.50
Laborers	9	23	22	30	56	74	87	77	21	34	433	4.00	1,732.00
Teams	4	6½	5	17	52	64	92	17	3	6½	267	8.00	2,136.00
Tractor operator	..	10	12	9	25	13	26	10	6	2	113	5.00	565.00
Tractor laborer	..	....	..	9	25	13	26	10	6	2	91	4.00	364.00
Roller man	..	....	..	..	..	..	..	11	1	....	12	5.00	60.00
Trucks (motor)	..	....	..	..	..	..	2	2	6	21½	31½	15.00	472.50
Shovel operated, days	..	12	13	12	25	24	44	10	8	10½	158½		
Tractor operated, days	..	10	12	9	25	13	26	10	6	2	113		

Labor cost	$8,718.67
Steam shovel: Coal, 112 tons at $7	784.00
Grease, waste, etc	50.00
Tractor: Gas 1,700 gal. at 15 cts	255.00
Oil, grease, etc	20.00
	9,827.67
Interest on tractor and 5-yd. trailer (first cost $5,000) at 5%	250.00
Depreciation on tractor and 5-yd. trailer	1,500.00
Interest on shovel (Erie A) $8,900 at 5%	445.00
Depreciation, say 25%	2,225.00
25,900 cu. yd. excavation moved $\frac{14,247.17}{25,900} = 0.55$	$14,247.67

Cost data by T. J. Loonie, Engineer in charge of contract.

Fine Grading for Pavement.—Geneva-Dresden Road, New York State, season of 1925.

Average daily output............220 sq. yd. of fine grading.
Labor cost per day (7 men), $28 ....$0.125 per square yard.
Common labor wage........................$0.40 per hour.

Rock Excavation.—Rock excavation is so variable in cost that no effort is made in the book to attempt to cover this item. Readers are referred to "Rock Excavation" by Gillette, Myron C. Clark Publishing Company and other excellent books for detail data on rock excavation costs.

Cost of Unloading Broken Stone.—For making estimates of the quantity of stone required the following data on imported limestone used on Road 5021 will be useful. The approximate sizes and actual weights of stone on this work were as follows:

No. 1 screenings, 5/8″ screen....... 2,550 lb. per loose cubic yard
No. 1A dustless screenings,
5/8″ screen with dust jacket...... 2,350 lb. per loose cubic yard
No. 2, 1 1/4″ screen................ 2,470 lb. per loose cubic yard
No. 3, 2 1/2″ screen................ 2,350 lb. per loose cubic yard
No. 4, 3 1/2″ screen................ 2,420 lb. per loose cubic yard

For purposes of estimating the cost of handling imported crushed limestone, the following weights for a cubic yard, based on railroad weights, will be used: No. 1, 2,600 lb.; No. 1A, 2,400 lb.; No. 2, ,500 lb.; No. 3, 2,400 lb.; No. 4, 2,400 lb.

Unloading Cars by Hand.—On Road 5021, with the author as engineer, a number of short-time (10-hr.) estimates made the cost of unloading per ton 12 to 13.5 cts.; and the cost per cubic yard 14 to 16 cts. This work was in 1910, and labor cost 17.5 cts. per hour. The shoveling was done from a steel platform, where it was dumped from hopper-bottom cars. When shoveled from inside the cars the cost may run as high as 20 cts. per cubic yard. The cost of shoveling is usually estimated at 15 cts. per cubic yard.

The time of loading 1 1/2 cu. yd. wagons by hand shoveling will range from 8 to 12 min.

Unloading Cars with Continuous Bucket Conveyor Elevator Plant.—Where there is a large quantity of stone to be unloaded and it is not possible to install an elevator plant on the existing track, it often pays to put in a switch. Six-car switches can be usually built for about $300. Where there are competing railroads no charge is usually made.

The following data are from Road 5046, season of 1910, with labor at 17.5 cts. per hour. The plant consisted of an ordinary continuous bucket conveyor operated by a 6-hp. gasoline engine; the bin had a capacity of 100 tons.

The average fuel consumption was 5 gal. of gasoline per day. Cost of fuel and oil averaged $1 per day.

The average force at the elevator was one foreman and three helpers.

A total of 4,670 tons, or 3,890 cu. yd., was unloaded at 8.4 cts. per ton, or 10.1 cts. per cubic yard.

The cost was divided as follows:

Setting up elevator at Scottsville	$ 60.00
Setting up elevator at Mumford	40.00
Setting up elevator at Wheatland	75.00
Labor of operation	194.00
Gasoline and oil	25.00
Total	$394.00

This method of unloading is not only cheaper than hand method: but also cheapens the cost of hauling, as no time is lost in loading the wagons. The time of loading a 1½ cu. yd. wagon from bin: ranges from 45 to 55 sec. There is also a saving in car demur-rage if the bin holds two or three carloads.

Elevator unloading saves about 4 cts. per cubic yard on tean time and about 5 cts. on the unloading, making a total saving pe cubic yard of about 9 cts. It usually costs about $150 to ship th plant and install it the first time, so elevator unloading is no adopted unless there are, at least, 2,000 cu. yd. of stone handled.

Unloading Cars from Coal Trestle.—These data are taken fron the Scottsville road repair work, Harold Spelman, engineer, seaso of 1910; labor at 20 cts. per hour; average force, two or three men A total of 4,400 tons was unloaded. The cost divided as follows

Rent of trestle	$125.00
Labor	232.00
Total	$357.00
Cost per ton	0.081
Cost per cubic yard	0.098

Unloading from Canal Boats.—The plant used consisted of portable bin and a horse-operated derrick; Road 5014; Jame Anderson, contractor. The average amount of stone unloade per day was 150 tons. The cost was 11.5 cts. per ton, or 14 ct: per cubic yard, divided as follows:

1 team and driver	$ 4.00 (10-hr. day)
1 foreman	2.50 (10-hr. day)
6 laborers, at $1.75 per day	10.50 (10-hr. day)
Total	$17.00 (10-hr. day)

Unloading Stone and Sand from Cars to Bin.—Clamshell cran Erie Type B. 10,000 tons stone and 6,000 tons sand unloaded i 50 working days. Average 320 tons per day.

Equipment, Erie clam Type B.

Force:

1 operator at 81 cts. per hour	$ 8.10
1 foreman at 45 cts. per hour	4.50
2 men in cars at 40 cts. per hour	8.00
Fuel and oil approximate	5.00
	$25.60

Approximate cost per ton 8 cts. exclusive of overhead and equipment charge.

Unloading Sand.—Hand shovelling from cars to trucks, Road 188, New York State, season of 1926, Geo. B. Gregg, cost inspector. Average 47 man-hours per car of 60 tons. 600 tons unloaded at a cost of 40.7 cts. per ton, exclusive of overhead.

Unloading Stone from Cars.—Hand shovelling to trucks. Road 188, New York State, season of 1926. Average 58 man hours per car of 60 tons; 720 tons unloaded at cost of 48.5 cts. per ton, exclusive of overhead.

Unloading Cement by Hand from Cars to Trucks.—On the Geneva-Dresden Road, New York State, 1926, with a common labor rate of 40 cts. per hour, 20,000 bbl. were unloaded at 6 cts. per barrel, exclusive of overhead.

On the Road 1639, New York State, season of 1922, with a common labor rate of 50 cts. per hour, 11,000 lb. were unloaded at [illegible].3 cts. per barrel, exclusive of overhead.

Cost of Loading Local Fence Stone into Wagons.—Road 5046, W. G. Harger, engineer, season of 1911,

Labor 17.5 cts. per hour.

[illegible],200 cu. yd., boulders loaded at a cost of 14 cts. per cu. yd.

A gang of six men will take from 9 to 13 min. in loading 1½ cu. yd., depending upon the size of the stone.

Road 495, E. E. Kidder, engineer, season of 1911,

Labor 1.75 cts. per hour.

[illegible]080 cu. yd., boulders loaded at a cost of 18.4 cts. per cu. yd.

Road No. 492, E. E. Kidder, Engineer, season of 1911,

Labor 17.5 cts. per hour, 300 cu. yd., loaded at 13.7 cts. per cu. yd.

Cost of Loading Filler at Pit.—On the Clover Street Road, Section [illegible], during the season of 1908, with the author as engineer and labor at 15 cts. per hour, 400 cu. yd. of sand filler were loaded at a cost of [illegible]2 cts. per cu. yd. On the Scottsville-Mumford Road, with labor [illegible]7.5 cts. per hour, 200 cu. yd. were loaded at a cost of 13 cts. per cu. yd.

Unloading Steel Beams.—On Road 188, New York State, season of 1926, with labor at 60 cts. per hour. 66,000 lb. of 30″ Bethlehem girder I-beams, 8 beams, 48′ long each were unloaded from cars to trucks by hand methods (jacks and bars).

96 man hours	$57.60
	=1.75 per ton
	=0.0009 per pound

Loading Plank.—Loading trucks from piles or cars, 2 men, 100 planks per hour, is average speed.

TEAM HAULING

Cost of Hauling Broken Stone.—Table 213 shows the cost of hauling stone on good roads as for repair work. The wagons were loaded from bins, so no time was lost in loading.

TABLE 213.—HAUL OF STOVE ON GOOD ROADS FOR REPAIR WORK

Road No.	Engineer in Charge	Price per Hour of Teams	Length of Haul, Miles*	Cost per Ton, Mile	Cost per Yard, Mile
1	Harold Spelman . . .	$0.50	1.8	$0.20	$0.24
1	Harold Spelman . . .	0.50	1.2	0.24	0.288
2	G. G. Miller	0.62	2.0	0.20	0.24
2	G. G. Miller	0.62	1.7	0.215	0.26
2	G. G. Miller	0.62	1.1	0.23	0.275
2	G. G. Miller	0.62	0.6	0.25	0.30
2	G. G. Miller	0.62	0.2	0.50	0.60
3	G. G. Miller	0.62	3.0	0.17	0.205
3	G. G. Miller	0.62	2.75	0.175	0.21
3	G. G. Miller	0.62	2.5	0.175	0.21
3	G. G. Miller	0.62	2.0	0.19	0.23
3	G. G. Miller	0.62	1.75	0.215	0.26
3	G. G. Miller	0.62	1.5	0.23	0.28

* This length of haul is the loaded length, complete round trip is twice thi engths cost is figured for length of loaded haul.

Road 1, 10-hr. day.
Roads 2 and 3, 8 hr. per day.

NOTE.—Cost per ton mile on Roads 2 and 3 equals the cost pe yard mile, for teams at 50 cts. per hour.

For hauling on bad roads for new construction, I have the follow ing personal data:

Clover Street Road, Section 1, season 1908; teams at 45 cts. pe hour; dump wagons loaded from bins; no time lost.

6,000 cu. yd., 0.6-mile haul cost 26 cts. per ton, or 31 cts. per yar mile.

4,500 cu. yd., 0.6-mile haul, cost 24 cts. per ton, or 29 cts. per cubi yard mile.

Scottsville-Mumford Road, season of 1911; teams, 45 cts. pe hour. 300 cu. yd., 1-mile haul (including a 5% sandy hill 1,20c long) cost 30 cts. per yard mile.

500 cu. yd., 0.5-mile haul (level road in bad condition) cost 30 ct: per yard-mile.

Hauling Field Stone and Filler.—This material was hauled fro fields and pits where it was loaded by hand. Considerable time wa thus lost.

On the Clover Street Road, Section 1, season of 1908, with th author as engineer, and teams at 45 cts. per hour, 10,000 cu. yd. c field stone were hauled an average of 1 mile for 36 cts. per yard mil

On the Scottsville-Mumford Road, season of 1911, with th author as engineer, and teams at 45 cts. per hour, 500 yd. of fiel stone were hauled 0.2 mile at 14 cts. per cu. yd., or 70 cts. per yar mile. On the same work 200 cu. yd. of filler were hauled 0.2 mil for 15 cts. per cubic yard, or 75 cts. per yard mile.

For all short hauls under ¼ mile the cost is high and practicall the same on account of the larger percentage of time lost in loadin

"Truck Hauling, 5 Ton Trucks.*—The daily mileage averaged 10.5 miles. The figures given are the average from over 100 trucks and are based on 1919 prices. They ran on an average 265 days of the year.

For some reason not stated the item of taxes has been left out.

RELATIVE IMPORTANCE OF OPERATING COST ITEMS

Rank	Cost item	Cost per day	Per cent of total cost
1	Depreciation	$ 5.29	20.3
2	Repairs and overhaul	5.11	19.6
3	Drivers' wages	4.96	19.0
4	Gasoline	3.42	13.1
5	Tires	2.29	8.8
6	Overhead	1.74	6.7
7	Insurance	1.25	4.8
8	Interest	0.76	2.9
9	Garage	0.74	2.8
10	Lubricants	0.42	1.6
11	License	0.11	0.4
	Totals	$26.09	100.0

Two of the largest items of cost, as shown above, are depreciation and drivers' wages; yet many one-truck operators establish their hauling rates without considering these items at all. It is little wonder that many of them fail in business even before their trucks are fully paid for.

The fixed charges in this table total about 38%. With this fact in mind the loss due to idle time can readily be visualized. Fixed charges continue whether the truck is operating or not, and the truck operating the most time will render greatest returns, other conditions being equal.

"Analysis of Factors Governing Motor Truck Operating Costs.—There are four principal methods by which truck operating costs are figured, namely, cost per mile, cost per day, cost per unit (ton, box, bag, gallon, bale, or other similar units) and cost per unit mile (ton mile, gallon mile, etc.). A great deal of confusion has resulted in the past through comparison of operating costs without considering the variable factors which increase or decrease costs on these various bases.

The following table shows how these four items vary through an increase in the factors listed in the first column. It is assumed, of course that operating conditions are equal.

TABLE.—VARIATION OF COST ITEMS

Variable factors	Cost per mile	Cost per day	Cost per unit	Cost per unit mile
Increase in daily mileage	Decrease	Increase	Increase	Decrease
Increase in truck capacity	Increase	Increase	Decrease	Decrease

* From Engineering Contracting.

In discussing these four cost bases it must be remembered thai the daily fixed costs are constant regardless of mileage, while the daily variable costs increase with an increase in mileage.

"**Cost per Mile.**—The "cost per mile" varies with the mile: operated per day. Obviously this cost will decrease as the mileag increases. The variable costs per mile should be practically th same whether the truck travels 10 or 50 miles in a day. Bu the fixed costs will be divided among a greater number of miles i the latter case, thereby reducing the total "cost per mile" unde what it would be if only 10 miles were traveled. A 5-ton trucl operating 50 miles per day may have a smaller "cost per mile' than a 3-ton truck operating only 10 miles per day. However an increase in truck capacity on the same daily mileage woul naturally increase the "cost per mile."

"**Cost per Day.**—The "cost per day" will vary with the mile operated per day. It is quite evident that this daily cost wil increase as the daily mileage increases. To the daily fixed charge must be added the daily variable charges which of course increas with the mileage, thereby increasing the "cost per day."

In comparing operating costs of different-sized trucks on th "cost per day basis" it is essential that the daily mileage of eac truck be known. It can readily be seen that a 5-ton truck operat ing only 10 miles per day should have a lower "cost per day" tha a 3-ton truck operating 50 miles daily under similar conditions.

The "cost per day" is affected also by the total number of day in the year that the truck is in actual operation. It is commonl assumed that a truck will operate 300 days a year, neglecting Sur days and holidays. In most cases this is much too high. Du to such factors as weather conditions, accidents, strikes, variatio in business demands, etc., this assumed total of 300 working day is frequently cut to 200 or less.

Assuming yearly fixed charges of $1800 on a 300-day basis woul give a daily fixed charge of $6. But if the truck operates only 20 days out of the year, the fixed charges will be $9 per day. Thi increase will be reflected in the "cost per mile."

"**Cost per Unit.**—Where mileage records are not kept, truc operators must be content with operating cost on the "cost pe unit" basis. The unit will vary with the kind of hauling involvec This unit may be tons, gallons, boxes, head of livestock, etc.

The "cost per unit" will increase as the average haul mileag increases. It is obvious that a ton hauled 10 miles will cost mor than a ton hauled 1 mile under the same conditions. Ther is very little difference in the fixed costs for each of the sizes c heavy trucks and since the variable costs on the various sizes d not increase in direct ratio with increase in size, the "cost per unit will vary with the truck capacity. The daily "cost per unit" wi decrease with an increase in truck capacity and will increase a the average haul mileage is increased.

"**Cost per Unit Mile.**—As a means of comparing operating cost of different trucks, there is probably no better basis than that of th "cost per unit mile." This is commonly worked out on the ton mile basis. It involves a record of units hauled and mileag

overed. Costs by this method will vary with the truck capacity nd the daily mileage. This "unit-mile cost" will decrease both vith an increase in truck capacity and with an increase in daily nileage. A 5-ton truck loaded to capacity will give a lower 'unit-mile cost" when operating 40 miles daily than when operatng only 20 miles daily. Likewise, a 5-ton truck loaded to capacity nd operating 20 miles daily should give a lower "unit-mile cost" han a 3-ton truck with capacity load covering the same mileage. arge truck capacity and high daily mileage tend to produce lower osts per unit mile.

Apparently there is a great variation in the methods used in rriving at the "unit-mile" or, as it is commonly figured, the ton-mile" cost. This involves not only a record of total tonnage nd total mileage, but also a record of the number of trips.

During the war one of our large motor truck companies sent out circular letter on operating costs to their sales representatives in vhich instructions were given to figure total cost per ton mile by ividing total cost per day by the number of miles driven times he number of tons carried. This apparently is the method freuently employed, but it leads to serious inaccuracies as can easily e illustrated.

Assume that a truck starts from point *A* and during the day nakes stops at points *B*, *C*, *D*, and *E* respectively, covering disances and carrying loads as follows:

TABLE.—TRIP-MILE-TON TABLE

Trip	Miles	Tons
A—B	10	4
B—C	5	1
C—D	5	2
D—E	10	3
Totals 4	30	10

By the method outlined in the sales letter the ton miles would be o × 10 = 300. Actually the ton-miles would be:

TABLE

Trip 1	10 × 4 =	40 ton-miles
Trip 2	5 × 1 =	5 ton-miles
Trip 3	5 × 2 =	10 ton-miles
Trip 4	10 × 3 =	30 ton-miles
Total		85 ton-miles

The first method is correct for a truck making one trip per day ith one load, but is entirely wrong in the case of a truck making nany trips daily with varying loads. In the latter case, if tonile costs are desired, it will be necessary to keep accurate records f mileage and loads between each stop where the load is changed. owever, in this type of trucking the cost per mile or cost per day usually more satisfactory.

When a truck is running on a regular route making a trip out to a certain point with a given load and back to the starting point with the same or a different load, the ton miles can be computed by multiplying the total mileage by the total load carried and dividing by twice the number of round trips. Suppose a truck travels from *A* to *B*, a distance of 10 miles, and returns with the following loads

TABLE.—ROUND TRIP LOADING TABLE

Round trip	Load out	Load in
1	5 tons	1 ton
2	2 tons	3 tons
3	4 tons	0 ton
4	1 ton	5 tons
Totals 4 round trips	12 tons	9 tons

The total mileage is 80 and the total load is 21 tons. Then b the formula as given the ton miles

$$\frac{80 \times 21}{2 \times 4} = 210.$$

Figured on the basis of the individual trips, the result is the same From the foregoing it can readily be seen that the basis of ton mile costs must be correct before dependable comparisons can b made.

Hauling Batched Concrete.—Geneva-Dresden Road, season c 1925. 15 Ford trucks, carrying 1 batch (21 cu. ft.) quick bi loading. Average haul bin to mixer 1.5 miles. Average 20 trip per day per truck or 30 miles loaded 60 miles total.

Initial cost of trucks	$360
Value at end of season	$150 ±
Drivers' wages	40 cts. per hour
Liability on trucks	$40 per season per truc

NOTE.—With longer hauls each truck travels about 100 mile per day (50 miles loaded).

Hauling Sand and Stone.—Road 188, New York State, season o 1926. 3½-ton trucks loaded by hand shoveling from cars. 3½ mile haul from cars to job Rent of trucks $30 per 10-hr. day.
750 tons of crushed stone hauled for $649,

Average	24. cts. per ton mil

Average time of trip 60 min.

600 tons of sand hauled for $410.55

Average	20.5 cts. per ton mil

Average time of trip 50 min.

Cost of Spreading Stone, Sand, and Screenings.—The following costs are for hand-shoveling methods. By the use of so-called manger spreaders in conjunction with truck hauling, the cost of spreading crushed stone for macadam construction can be reduced 50% from hand-shoveling and raking methods.

COST OF SPREADING STONE AND BINDER

Table 214, page 1167, gives the cost of spreading broken stone on several New York State roads.

The ratio of the loose to the rolled depths varies with the size of the fragments and the depth of the course. Table 215, page 1168, gives the averages of the results obtained from 1000 test holes made by the writer on three separate roads. The last column of the table also gives the weights of No. 3[1] and 4[2] stone required to make a cubic yard of rolled macadam. The amount of filler or binder per cubic yard of rolled macadam is given in Table 216, page 1168.

The excessive amount of filler required for the 2-inch bituminous macadam, Table 216, was due to a layer of screenings placed under the No. 3 stone, all of which did not act as a filler. The small amount required for the 3-inch bituminous macadam was due to the fact that the bituminous binder partially filled the voids before the screenings were applied.

The ratio of loose to rolled depth for boulder subbase is variable.

If the size of boulders is practically the same as the depth of the course, that is, if there is only one layer of stone, the loose depth and the rolled depth will be the same. Where there are two or three layers of boulders the ratio is, approximately, 1:1.25, *i.e.*, a 12-inch, rolled depth would require 15-inch loose depth for boulders averaging 5 to 6 inches in diameter.

Table 214.—Spreading Stone

Reference No.	Engineer	Labor Wage	Depth of Loose Spread	Amount Spread	Cost per Ton	Cost per Cu. Yd.
1	Harold Spelman ..	$0.20	4 in.	7000 tons	$0.066	$0.08
2	W. G. Harger	0.175	5⅓ in.	6000 cu. yds.	0.05	0.06
2	W. G. Harger	0.175	4 in.	4500 " "	0.07	0.083
3	W. G. Harger	0.20	6 "	1000 " "	—	0.05
		Placing sub-base stone				
3	W. G. Harger	0.175	7 in.	100 " "	—	0.10
3	W. G. Harger	0.175	10 " gravel	200 " "	—	0.04
4	E. E. Kidder......	0.175	6 "	267 " "	—	0.07
[1]5	E. E. Kidder......	0.175	6 "	1082 " "	—	0.12

[1] Sub-base bottom course. The cost includes sledging of all large stone.

[1] No. 3 stone 1½″ to 2½″.
[2] No. 4 stone 2½″ to 3½″.

TABLE 215.—RATIO OF LOOSE TO ROLLED DEPTH

Size of Stone	Rolled Depth	Loose Depth	Ratio	Weight per Cubic Yard Rolled Measure[2]
No. 4	4 in.	5.2 in.	1.3	3120 lbs.
No. 4	3 "	3.8 "	1.27	3050 "
No. 3	3 "	3.9 "	1.3	3120 "
No. 3	2 "	2.4 "	1.2	2880 "

[2] Weight of cubic yard (loosemeasure) 2400 lb.

TABLE 216.—AMOUNT OF FILLER AND BINDER REQUIRED

Kind of Course	Kind of Filler	Amount of Filler per Cu. Yd. of Rolled Macadam	Weight of Screenings per Cu.Yd. of Rolled Macadam
Bottom stone	Sand	0.35 cu. yds.	—
Waterbound top[3]...	No. 1	0.50 " "	1300 lbs.
3-in. Bit. mac. top[3].	Nos. 1A and 2	0.37 " "	900 "
2-in. Bit. mac. top[3].	No. 1A	0.60 " "	1440 "
Sub-base	Gravel	0.33 " "	—

[3] Weight of cubic yard (loose measure) 2400 lb. Filler for top course includes wearing coat.

Cost of Spreading Filler by Hand from Piles Spaced 20′ to 30′ Apart.—On the Clover Street Road, Section 1, during the season of 1908, with labor at .15 cts. per hour, 400 cu. yd. of sand filler were spread at a cost of .10 cts. per cu. yd. On the Scottsville-Mumford Road, with labor at 17.5 cts. per hour, the cost of spreading 200 cu. yd. was 20 cts. per cubic yard. This includes some hand brooming but most of the brooming was done by a broom attachment on the roller.

Cost of Spreading No. 1A and No. 2 Stone for Bituminous Macadam Top Courses and Brooming Same.—A layer of No. 1A, ½″ deep, was spread over the bottom course. On this was spread 2½″ of No. 3 stone. After rolling, bitumen was poured over this course and a ¾″ layer of No. 2 stone spread and rolled; the excess of No. 2 was broomed off and a ⅜″ wearing coat of No. 1A placed.

The cost of spreading for a 2″ top was as follows:

Cost[1] of No. 1A and No. 2 per cubic yard.....	$0.282
Cost[2] per ton of No. 1A and No. 2...........	0.210

Eight hundred tons of this material was handled with labor costing 17.5 cts. per hour.

[1] No. 1A are dustless screenings.
[2] No. 2 is ⅝″ to 1½″ size.

For a 3″ top course the procedure was the same, omitting the layer of No. 1A under the No. 3 stone. The cost of handling 400 tons for the 3″ course was as follows:

Cost per cubic yard of No. 1A and No. 2	0.31
Cost per ton of No. 1A and No. 2	0.26

Cost of Spreading Screenings with Cross-dump Wagons.—Wet dust screenings for water-bound macadam cannot be successfully spread in this manner. For spreading dry dust screenings, No. 2 stone or dustless screenings for bituminous macadam, this method has proved the cheapest and most satisfactory. On Road 5046, season of 1910, a number of short-time estimates made the cost of spreading by this method about 6 cts. per cubic yard. The cost of brooming is slightly increased over that required by the hand-spreading method, but not enough to counteract the advantage in the use of the wagon spreading. On the Clover Street Road, season of 1908, 1,000 cu. yd. of screenings were thus spread for about 7 cts. per cubic yard.

SPREADING BITUMINOUS BINDER AND SURFACE COATS

Hand Methods.—The following data are taken from Road 5021, season of 1910. Bituminous macadam, penetration method:

Labor.

Kettleman	$0.20 per hour
Spreaders	0.20 per hour
Plain labor	0.175 per hour
Teams	0.45 per hour

Apparatus.

4-bbl. kettle (coal burner)	Bitumen heated
2-bbl. kettle (wood burner)	to 400°F.
12-ton Kelly roller	

Spreading pots having a vertical slot 1/8″ wide.

Organization.

Rollerman acting as foreman
1 spreader
1 kettleman
3 laborers

Average speed 350′ of 16′ road, per day.

Quantities.

16,850 gal. laid in one coat covered 13,330 sq. yd., or 1.26 gal. per sq. yd.

Cost per gallon	Unloading and hauling 1/2 mile	$0.0015
	Heating	0.0032
	Spreading	0.0032
	Rolling and supervision	0.0051
	Total	$0.0130
Bituminous material f.o.b. Caledonia		0.0950
	Total per gallon	$0.1080

Second quantity.

Forty-two thousand gallons covered 24,000 sq. yd. in one coat, an average of 1.75 gal. per square yard.

Cost per gallon	Unloading and hauling 1¾ miles	$0.0032
	Heating	0.0040
	Spreading	0.0039
	Rolling and supervision	0.0042
	Total	$0.0153
Bituminous material f.o.b. Caledonia		0.0950
	Total per gallon	$0.1103

Cost of Applying Bituminous Binder. Road 5046, *Penetration Method.*

18,890 gal. spread on 12,378 sq. yd. in one coat, of 1.52 gal. per sq. yd.

Apparatus.

5 2-bbl. kettles (wood burners). Fuel. Used barrel staves and some extra wood.
1 10-ton Buffalo Pitts Roller.
Spreading hods.

Organization.

	Per Hour
1 foreman	$0.30
2 pourers, each	0.25
5 kettlemen, each	0.20
2 spreaders of No. 2, each	0.20
4 helpers, each	0.175

Labor of Placing. Cost per gallon.

Fuel	$0.001
Kettlemen	0.005
Pouring	0.003
Helpers	0.007
Supervision	0.002
Total	$0.018
Material f.o.b. Scottsville	0.093
Total per gallon	$0.111

Mechanical Application.—Barrett Company is doing this work (1925 in western New York) for 4 cts. per gallon for cold tar work and 5 cts. per gallon for binder grade (hot tar). This price includes hauling up to a maximum 50-mile limit and the price is probably based on an average 20- to 25-mile haul (plant to job). The cost of hauling is approximately 2 cts. per gallon which makes the cost of applying from 2 to 3 cts. per gallon.

ROLLING AND PUDDLING

COST OF ROLLING

In the following costs lubricating oil is not included, as no reliable data were obtained as to the quantity used. Gillette's "Handbook of Cost Data" gives this item as 30 cts. per day; using this amount would increase the costs given below from 0.2 to 0.3 ct. per cubic yard. The amount of coal used was variously estimated at from 450 to 500 lb. per day. As before mentioned, items of depreciation, repairs of plant and equipment, and interest are not included in the cost per cubic yard of stone consolidated.

On Road 5025, under E. E. Kidder, engineer, during the season of 1910, the cost of rolling 3,400 cu. yd. of bottom stone and 1,700 cu. yd. of top stone, loose measure, was as follows:

Rollerman, 4 months, at $90	$360
Coal, ¼ ton per day, at $2.70 per ton, 80 days	55
	$415

The time and cost were divided as follows:

⅙ on subgrade	$ 69
⅓ on bottom stone 4″ deep	138
½ on bituminous top stone, 2″ deep	208

There was no cost for water. The roller worked 80 days in 4 months. The cost of rolling per cubic yard of loose material was: bottom stone, 4 cts., and top (bituminous macadam) 12 cts.

On Road 492, E. E. Kidder, engineer, season of 1910, the cost of rolling 3,700 cu. yd. of 4″ bottom course was 3 cts. per cubic yard, and for 3,200 cu. yd. of water-bound top stone 5 cts. per cubic yard. Both quantities refer to loose measure. The roller worked 74 days in 3 months. The puddling was done by a pipe line and hose and brooms attached to the roller. The rollerman's wages were $90 per month and coal $2.75 per ton.

On Road 5021 the cost of rolling a 3″ bituminous top course per cubic yard of loose material was 9 cts.; for a 2″ top 11 cts.

On Road 5046 a roller working 111 days consolidated 1,850 cu. yd. of field stone subbase, 4,300 cu. yd. of bottom stone, and 2,150 cu. yd. of top stone, loose measure. The depth of the subbase was 6″ (rolled measure), the bottom course 4″, and the top course 2½″, bituminous macadam. The rollerman's wages were $90 per month and coal cost $2.75 per ton for ¼ ton per day. There was no cost for water. The costs were divided as follows: subbase, 3.5 cts.; bottom stone, 4.5 cts.; top stone, 10.5 cts. per cu. yd., loose measure.

PUDDLING WATER-BOUND ROADS

There are two methods of puddling: first, by pipe line and hose; second, by sprinkling carts.

In the first method a 1½ or 2″ pipe is laid along the road with taps every 200 to 300′. The road is wet down by a hose fastened to these taps and sprayed on by a nozzle, or the hose is fastened

to a sprinkling attachment on the roller, which throws the water directly onto the wheels; this method is cheaper and more satisfactory than using sprinkling carts, but to work well a pressure of 125 lb. should be maintained at the pump, which requires a better pumping apparatus than contractors usually have. A very satisfactory plant, used near Rochester, N. Y., consisted of a Gould Triplex Pump, operated by a 6-hp. gasoline engine; the relief valve at the pump was set at 120 lb.

The cost of such puddling on Road 492 for 3,000 cu. yd. of top course was 5 cts. per cu. yd.; on Road 294 for 4,000 cu. yd. of top course it was 6 cts. This cost includes pumping, helper tending hose, and rollerman. Brooms on the roller were used which materially reduced the cost of brooming the screenings. No charge for water, no allowance made for laying the pipe line; this last charge is included in the lump-sum item of installing plant for a water-bound road, page 1261.

Gillette, in his handbook, gives sprinkling by carts approximately 10 cts. per cu. yd. of top course, which includes sprinkling the subgrade as well as puddling the top course. As the subgrade is rarely sprinkled, his data reduced to the conditions cited on Roads 492 and 294 would give approximately 6 cts. per cubic yard of top course. To this is added the cost of rolling, or about 4 cts. which makes the cost of puddling by this method about 10 to 12 cts., or about twice the amount of the first method.

E. A. Bonney, on the Hamburg-Buffalo Road, from a metered supply of water, states the amount required to first puddle a 3″ top course varies from 50 to 55 gal. per cubic yard of top course, and the amount needed for the second puddle will be considerably less.

H. P. Gillette states, in a monograph on the Economics of Road Construction, that 30 gal. of water per cubic yard will puddle a road. E. E. Kidder states that approximately 80 gal. are required per cubic yard of top course for two puddles. The author's experience agrees with the larger quantities.

COST OF CRUSHING STONE

As a basis for all cost estimates for crushing, it is necessary to crusher know something of the percentage of the different sizes of the output. Tables 218 and 219, pages 1179 and 1181, give typical data on size output. Table 217, page 1173, gives the results of tests made by Archer White during the season of 1910 on ordinary limestone and sandstone boulders composing the average field stone. The crusher used was the largest Acme portable crusher. The tailings were recrushed and the stone divided into four grades: No. 1, ¾″ screen; No. 2, 1½″; No. 3, 2½″, and No. 4, 3½″. From these data it may be seen that 1 cu. yd. of field stone makes 1 cu. yd. of crushed stone, and that it takes approximately 1.8 cu. yd. of field stone to make 1 cu. yd. rolled measure of sizes Nos. 3 and 4. The crusher toggle was set to produce both top and bottom stone sizes.

The cost of labor was 20 cts. per hour. The engineman of the crusher plant received 25 cts. per hour and the foreman 30 cts. per

TABLE 217.—SIZES AND PROPORTIONS OF CRUSHER RUN

Reference No.	Cu. Yds. Field Stone Delivered to Crusher	Cu. Yds. Crushed Stone Produced	Number 1 $\frac{3}{4}''$ Screen		Number 2 $\frac{3}{4}''$ to $1\frac{1}{2}''$		Number 3 $1\frac{1}{2}''$ to $2\frac{1}{2}''$		Number 4 $2\frac{1}{2}''$ to $3\frac{1}{2}''$		Kind of Material
			Cu. Yds. Produced	% of Total Output	Cu. Yds. Produced	% of Total Output	Cu. Yds. Produced	% of Total Output	Cu. Yds. Produced	% of Total Output	
1	195	190	36	19	18	9	64	34	72	38	Sandstone and limestone
2	187	182	32	$17\frac{1}{2}$	10	$5\frac{1}{2}$	70	$38\frac{1}{2}$	70	$38\frac{1}{2}$	Limestone
3	196	202	36	18	14	7	76	38	76	37	Limestone and sandstone
4	190	216	40	18	18	8	79	37	79	37	Sandstone
5	173	172	32	19	28	16	62	36	50	29	Poor sandstone
6	189	184	36	$19\frac{1}{2}$	16	9	*	—	132	$71\frac{1}{2}$	Limestone
7	165	170	32	19	22	13	*	—	116	68	"
8	—	—	30	16	24	13	*	—	60	63	Soft sandstone

*No. 3 and No. 4 size mixed and placed on grade.

hour. The field stone was loaded from a pile near the crusher intc small dump cars running on a movable track. The loaded cars were drawn to the crusher by a small hoisting engine. The cost o bringing the field stone to the crusher pile is not included. The force loading consisted of one foreman, eleven laborers, and one engineman. The force crushing consisted of one foreman, fou laborers, and one engineman. In 8 days 1,500 cu. yd. were crushed The cost of the entire output per cubic yard of loose measure was divided as follows:

Loading stone for crusher	$0.133
Hauling to crusher	0.013
Feeding to crusher	0.061
Engineer to crusher	0.013
Fuel and oil	0.030
Loading crushed stone from bins	0.010
Total	$0.260

Crushing Granite Hardheads and Sandstone.—The followin data are from the records of the Clover Street Road, Section 1, sea son of 1908. Labor cost 15 cts. per hour and the enginema received $3 per day. The crusher used was a 10″ × 20″ Climax A total of 5,000 cu. yd. of granite were crushed at a cost per cubi yard, loose measure, of 19 cts.; 7,000 cu. yd. of sandstone boulder were crushed at a cost of 10.3 cts. per cu. yd., loose measure. Thes figures are for the total output of the crusher and include the cos of feeding to the crusher, the pay of the engineman, coal, oil, bu not the delivery to the crusher. On the Scottsville-Mumford Roa under similar conditions the cost varied from 13 cts. for granite an sandstone to 19 cts. for granite hardheads per cubic yard of loos measure.

Crusher force on the Clover Street and Scottsville-Mumford road as follows:

1 foreman	$4.00
5 men feeding crusher	2.00 each
1 man tending screen	2.00
1 engineer	3.00
Fuel and oil	4.00

Where bottom stone alone is being crushed from local materia the crusher is set to produce a larger amount of No. 4 stone, an the proportion of the screenings to the No. 3 and No. 4 sizes i different than given in Table 217.

In the following data from Road 5046, Scottsville-Mumford mentioned above, the No. 3 and No. 4 and tailings were used as th bottom course stone, the tailings being broken into proper size after the stone was spread by knapping hammers. The cost o knapping will vary from 1 to 3 cts. per cubic yard of loose botton stone, depending on the number of tailings produced. When th crusher is set correctly to deliver a good grade of stone for botton course, this charge should not amount to over 1 ct. per cubic yar

of total output and is properly chargeable against crushing, which increases the crushing costs given above from 13 to 14 cts. and from 19 to 20 cts.

The sizes of screens were 5/8″, 1 1/4″, 2 1/2″, and 3 1/2″.

Crusher Set-up, No. 1.—60% granite, 30% sandstone, 10% soft rock.

Total screenings, No. 1	240 cu. yd.
Total No. 2	no record
Total No. 3, 4, and tailings	1,500 cu. yd.

Crusher Set-up, No. 2.—50% granite, 40% sandstone, 10% soft rock.

Total screenings	350 cu. yd.
Total No. 2	no record
Total No. 3, 4, and tailings	2,600 cu. yd.

For this same road the amount of field stone required per loose yard of bottom stone is shown by the following figures. Approximately 1.5-yard loads were drawn to and from crusher.

Date	Number Loads of Field Stone Crushed	Number Loads of No. 3 and No. 4 and Tailings Drawn from the Crusher
1911		
April 24	114	93
" 25	86	70
" 26	87	69
May 5	104	84
" 6	101	82
" 8	106	85
" 9	99	78
" 10	86	72
" 11	107	95
" 12	110	80
" 13	102	83
Totals	1102 loads 1653 cu.yds.	891 loads 1336 cu. yds.

On this work 1.24 cu. yd. field stone produced 1 cu. yd. loose measure bottom stone, and 1.61 cu. yd. field stone produced 1 cu. yd. bottom stone rolled measure.

Table 217, page 1173, gives 1.8 cu. yd. field stone to 1 cu. yd. rolled macadam, but this apparent difference is explained by the fact that the tailings were recrushed and the crusher set closer to produce top as well as bottom stone, consequently the per cent of No. 1 and No. 2 is higher than for the data just given.

Data obtained by Frank Bristow, First Assistant Engineer, New York State Department of Highways, indicates that 1 cu. yd. of field stone produces 1.1 cu. yd. crushed stone when separated by screens of ½″, 1¼″, 2½″, and 3½″; this is slightly more than the writer's experience has indicated.

When local stone is crushed for bottom only, the screenings are used as filler for that course, and in a case of this kind it is necessary to know how much additional filler must be estimated. Take the case of the Scottsville-Mumford Road (crusher set-up No. 2) given above. Twenty-six hundred cubic yards loose measure will consolidate under the roller to approximately 2,000 cu. yd. of rolled bottom stone. This will require 2,000 × 0.35 = 700 cu. yd. filler. The amount of screenings produced in crushing 2,600 cu. yd. of bottom was 350 cu. yd., showing that for cases similar to the one given, half of the total filler required must be obtained from other sources.

Cost of Sledging Boulders.—A certain percentage of the fence stone must be broken to reduce them to a proper size for crushing. This is done by blasting or sledging; where the boulders need to be broken only two or three times to reduce them to usable sizes, sledging is the cheaper method. The cost of both of these methods is so variable that any cases cited would not be of much value. As given on page 1130, under Standard Estimates, the author allows arbitrarily 60 cts. per cu. yd. for all boulders actually sledged or blasted, and in making estimates the per cent to be treated in this manner is approximated roughly.

As a matter of interest Gillette, in his cost data on rockwork, gives the cost of sledging small sandstone boulders as approximately 5 cts. per cu. yd., and the cost of mud capping at about 35 cts. per cu. yd. 1910 scale of costs.

COST OF CRUSHING (*Continued*)

The following data are taken from the Report of the Massachusetts Highway Commission and refers to work done in Newton, Mass. The crushed stone was divided into the following sizes:

Tailings..........	205 cu. yd.	17.5%
2½″ stone........	692 cu. yd.	57.0%
Screenings and 1″.	300 cu. yd.	25.5%
Totals............	1,197	.... 100.0%

The material was cobblestones and labor probably cost 20 cts. per hour, teams, 45 cts. The cost per cubic yard at the crusher was 44.5 cts., or 33 cts. per ton.

The cost per cubic yard was divided as follows:

Teaming to crusher.......	$0.314................	70.6%
Feeding to crusher........	0.033................	7.4%
Engineer of crusher.......	0.029................	6.5%
Repairs, coal, oil, etc.....	0.045................	10.1%
Watchman............	0.024................	5.4%
Total................	$0.445	100.0%

Material. Conglomerate.

Amount broken........................ 1,288 cu. yd.
Amount broken per hour.............. 8.9 cu. yd.

Divided as follows:

		Weight per Cubic Yard Loose
Tailings, 378 cu. yd	29.3%	2,549 lb.
2½" stone, 668 cu. yd	51.9%	2,368 lb.
Screenings and 1", 242 cu. yd.	18.8%	2,727 lb.

Cost per cubic yard in bins at crusher.................. $1.112
Cost per ton in bins at crusher........................ 0.885

Divided as follows:	Cost	Per Cent
Powder and repairs	$0.018	1.6
Labor drilling	0.249	22.3
Sharpening drills and tools	0.023	2.1
Breaking stone for crusher	0.420	37.8
Loading stone for crusher	0.127	11.4
Hauling stone for crusher	0.062	5.6
Feeding crusher	0.053	4.7
Engineer for crusher	0.038	3.5
Coal, oil, and waste	0.050	4.5
Moving and setting crusher	0.023	2.1
Watchman	0.049	4.4
Total	$1.112	100.0

Material. Greenish trap.

Amount broken........................ 3,155 cu. yd.
Amount broken per hour.............. 7.7 cu. yd.

Divided as follows:

		Weight per Cubic Yard Loose
Tailings, 1,004 cu. yd	31.8%	2,457 lb.
2½" stone, 1618 cu. yd	51.3%	2,383 lb.
1" stone, 323 cu. yd	10.2%	2,277 lb.
Screening, 210 cu. yd	6.7%	2,585 lb.

Cost per cubic yard in bins at crusher.................... $0.898
Cost per ton in bins at crusher.......................... 0.745

Divided as follows:	Cost	Per Cent
Labor, steam, drilling	$0.092	10.3
Coal, oil, water, powder, etc	0.084	9.4
Sharpening drills and tools	0.069	7.7
Breaking stone for crusher	0.279	31.0
Loading stone for crusher	0.098	11.0
Hauling stone for crusher	0.072	8.0
Feeding crusher	0.053	5.9
Engineer of crusher	0.031	3.4
Coal, oil, waste, and repairs of crusher	0.079	8.8
Other repairs	0.041	4.5
Total	$0.898	100.0

W. E. McClintock, engineer, Chelsea, Mass., season 1887:

Labor	$0.20 per hour
Teams	0.45 per hour

Material. Trap rock.

Amount broken	1,718 tons

Stone delivered at crusher by subcontractor for 75 cts. per ton

Cost. Tools	$0.013
Oil, waste, etc.	0.016
Fuel	0.050
Stone at crusher	0.750
Crushing (labor)	0.194
Total per ton	$1.023

Dustless Screenings.—The construction of bituminous macadams requires a dustless screening product referred to in the beginning of the chapter as No. 1A; it is obtained by rescreening the ordinary screenings (¾″ product) to remove the dust; the percentage of dust in the ordinary screenings will vary according to the stone crushed and the setting of the crusher jaws. The author has no reliable data for small crushing plants, but through the courtesy of the Buffalo Cement Company the following data are given for their output of limestone screenings at Buffalo, N. Y.

Size of screen opening for ordinary screenings	¾″
Size of dust screen openings	⅛″

Cubic yard of dust for 1 cu. yd. ordinary screenings	0.3[illegible]
Cubic yard of dustless screening 1 cu. yd. ordinary screening	0.6[illegible]

The same data from the Leroy plant of the General Crushed Stone Company give:

Size of screen openings for ordinary screenings	⅝ to 1 1/16″
Size of dust screen openings	¼ to 5/16″
Cubic yard of dust per cubic yard ordinary screenings	33%
Cubic yard of dustless screenings per cubic yard ordinary screenings	67%

Percentage of screenings to total output for Leroy limestone approximates 15%.

The above furnished to the writer through the courtesy of the General Crushed Stone Company, of Easton, Pa.

QUARRYING AND CRUSHING—SMALL QUARRIES

Cost Data.—New York State, season of 1925, Roads 5270 and 5271, Francis Carroll, engineer.

Local Quarry.—3′ depth stripping. Soft sandstone (French coefficient of wear 7 to 13). Quarry face 8 to 10′ high.

Total Quantities and Sizes of Output.

19,000 tons crushed stone 1½″ to 4½″ in size.
7,000 tons screenings passing ¾″ round screen.
4,000 tons No. 2 stone (¾ to 1½″ size).

30,000 tons total output.

Approximate average daily output 300 tons.

Stone used for macadam bottom course.

)uarrying and Delivery to Crusher. Equipment.
Team and slip scrapper for stripping.
Ingersoll-Rand portable air compressor and 2-drill outfit for drilling.
Osgood steam shovel for loading to Kopple Cars Champion friction hoist.

:ost of Quarrying per Day.

Stripping 1 man and team	$ 6.00	
Drilling outfit, rent per day	20.00	
15 gal. gas per day	3.00	
Steam shovel with runner and fireman (rent)	52.50	
Coal and oil	3.50	
Dynamite 60 lb. at 20 cts.	12.00	
2 drillers at $5	10.00	
2 men breaking big stone at $4.50	9.00	
1 man operating cars at $5	5.00	
Total	$120.00	= 40 cts. per ton.
:ost of quarrying exclusive of labor overhead	$0.40	per ton
Labor overhead (approximately)	0.05	
:ost of stone (quarry rights)	0.06	
Total cost of quarrying	$0.51	per ton total output of crusher

rushing. Equipment.
No. 6 Champion 12 × 26″ (300-ton capacity).
50-hp. electric motor (initial cost $500).
15′ screen, 4 sections.
¾″ screen 4′ long.
1½″ screen 4′ long.
4½″ screen 7′ long.
Tailing belt for stones over 4½″.
Bin 24′ long, 12′ high, 11′ wide.
Elevator 39′ long, 18 buckets.

ost of Crushing per Day.

Electric power	$10.00
2 men on platform	12.00
1 man on hoist	5.00
1 mechanic	7.00
1 man tending loading	5.00
	$39.00
Labor overhead	5.00
Approximate rental value of equipment	40.00
Approximate total per day	$84.00
Per ton of total output	0.28

'otal cost per ton quarry and crushing 80 cts. per ton total output of crusher.

TABLE 218.—APPROXIMATE PER CENT OUTPUT OF ORDINARY ROAD CRUSHER (VOLUME)

Rock	Passing ¾″ screen, %	¾ to 1½″, %	1½ to 2½″, %	Above 2½″, %
Limestone	15 to 20	5 to 13	30 to 40	30 to 40
Sandstone	16 to 22	8 to 15	30 to 40	25 to 35
Granite	10 to 15	10 to 15	35 to 40	35 to 40
Gneiss	8 to 15	9 to 15	35 to 40	35 to 45
Trap rock	6 to 10	8 to 12	35 to 45	40 to 50
[1] Mixed sandstone and limestone	16 to 21	7 to 14	30 to 40	30 to 40
[1] Mixed granite and sandstone (cobbles)	12 to 17	8 to 12	30 to 40	35 to 40

[1] Fence stone output.

NOTE.—1 cu. yd. field stone cobbles makes 1 cu. yd. crushed stone screened-out sizes (loose measure).

1 cu. yd. solid quarry stone makes approximately 1.9 cu. yd. crushed stone screened-out sizes (loose measure).

1 cu. yd. field stone cobbles will produce from 0.85 to 0.92 cu. yd. (0.9 cu. yd. average) loose measure crusher run with the smaller amount for soft rocks and the larger amount for hard rocks.

1 cu. yd. solid quarry excavation will produce from 1.6 to 1.75 cu. yd. (1.7 cu. yd. average) loose measure crusher run.

Consolidation.

The ratio of loose to roiled depth for crushed stone and gravel is about as follows:

Gravel 1.2
Crusher run 1.2 to 1.3 (average 1.25)
Screened uniform sizes 1.3

Approximate Amount of Boulders and Quarry Stone per Cubic Yard Macadam Rolled Measure

	1½ to 3½"	Boulders	Solid quarry
1 cu. yd. rolled measure	Screened sizes	1.7 cu. yd. ±	0.9 cu. yd. ±
1 cu. yd. rolled measure	Crusher run	1.4 cu. yd. ±	0.74 cu. yd. ±

Weights of Solid Rock (New York State)

	Pounds per cubic foot	Pounds per cubic yard
Limestone	167 to 171	4500 to 4600
Sandstone	155 to 169	4200 to 4600
Granite	165 to 171	4500 to 4600
Gneiss	167 to 185	4500 to 5000
Trap rock	180 to 185	4800 to 5000
Syenite	171 to 184	4600 to 5000

Approximate Weights of Crushed Stone Per Loose Cubic Yards

Rock	Passing ¾" screen, ordinary screenings	¾ to 1½"	1½ to 2½"	Above 2½"
Limestone	2550 ±	2350 ±	2400 ±	2400 ±
Sandstone	2450 ±	2300 ±	2350 ±	2350 ±
Granite	2500 ±	2350 ±	2400 ±	2400 ±
Gneiss	2600 ±	2500 ±	2550 ±	2550 ±
Trap rock	2650 ±	2550 ±	2600 ±	2600 ±

Crusher run 200 to 500 lb. per loose cubic yards more than weight of screened sizes. Average 300 lb. heavier.

NOTE.—Some authorities give the screened size weights about 100 lb. per cubic yard more or less than this table.

TABLE 219.— TYPICAL CRUSHER OUTPUT—DIFFERENT ARRANGEMENTS OF SCREENS AND MIXED SIZES—SANDSTONE (FRENCH COEFFICIENT OF HARDNESS 7.0) TOTAL SCREENED-OUT SIZE OUTPUT 1,000 CUBIC YARD LOOSE MEASURE

Dust[1] passing ¼″ screen	No. 1 dustless screenings ¼ to ⅝″	No. 2 ⅝ to 1½″	No. 3 1½ to 2¾″	No. 4 2¾ to 3¾″	Remarks
90 cu. yd. ±	130 cu. yd. ±	120 cu. yd. ±	350 cu. yd. ±	310 cu. yd. ±	Screened-out sizes
← 200 cu. yd. ± →		← 760 cu. yd. →			Mixed sizes
← 90 cu. yd. ± →	← 820 cu. yd. ± →				Mixed sizes
← 110 to 120 cu. yd. →	← 780 cu. yd. ± →			....	No. 4 recrushed
← 890 cu. yd. ± →					Crusher run

[1] Of the material passing ¼″ screen approximately 10% passes No. 80 screen and 20% passes No. 40 screen.

WEIGHTS OF GRAVEL

Continental Sand Company, Rochester N. Y.—Dolomit Gravel

Pit-run gravel.......................... 3,000 lb. per cubic yard (loose
Washed sand.......................... 2,700 lb. per cubic yard (loose
Washed gravel:
15 % passing ½″ screen
35 % ½″ to 1½″ screen .... 2,500 lb. per cubic yard (loose
50 % 1½″ to 2½″ screen
Output 45 % washed sand, 55 % screened gravel.

Valley Sand Company

Washed sand.......................... 2,700 lb. per cubic yard (loose
Washed gravel (mixed sizes).............. 2,500 lb. per cubic yard (loos
Output 33 % sand, 66 % gravel.

Note.—Above weights are for dry material. Wet sand will run as hig as 3,200 lb. per cubic yard.

WEIGHTS OF CRUSHED STONE

Crusher Run Stone.—Crusher run stone will run from 200 t 500 lb. per yard higher than the weight of screened-out unifor sizes.

For limestone weighing 170 lb. per solid cubic foot and approx mate 2,400 lb. per loose cubic yard screened sizes. Crusher ru will weigh from 2,650 to 2,800 lb. per cubic yard loose measur according to Harger, Gilmore, and Whitmore Rauber and Vicinu See page 1159 for weights of uniform screened sizes of limestone.

COST OF STONE-FILL BOTTOM COURSE

The following data are taken from Road 5021, season of 191 labor cost 17.5 cts. per hour, teams 40 cts. per hour.

The amount placed was 10,000 cu. yd. rolled measure. Th average rolled depth was 1.1′. The surface was carefully brough to line and grade, allowing a variation of 1″ either above or belo which inequality was taken out with the top stone. A 3″ bitum nous top course was placed directly on this fill. The top layer bottom stone was sledged to reduce all stones to 8″ or unde Flint stone was used to fill the top 6″ and to surface the rough fi The bottom course was of fence stone, hauled, on an average, abo ½ mile. I estimate that 1 cu. yd. rolled measure requires 1.: cu. yd. loose. The cost of the bottom course per cubic yar rolled measure was $1.03, divided as follows:

Loading 1.25 cu. yd.	$0.19
Hauling 1.25 cu. yd. ½ mile	0.20
Placing 1.25 cu. yd. and rolling	0.24
Sledging	0.15
Flint	0.10
Cost of fence stone	0.15
Total, per cubic yard	$1.03

Cost of Subbase Bottom Course.—Road 495, Parma Corners-Spencerport. E. E. Kidder, engineer. 1082 cu. yd. placed, average depth 6″. Not much sledging required.

Cost of stone, 1 cu. yd	$0.10
Loading, per 1 cu. yd	0.184
Hauling 1 mile	0.30
Laying, sledging, and spreading filler	0.136
Rolling	0.02
Superintendence	0.02
Cost of filler in pit nothing (gravel used)	0.00
Loading 1/3 cu. yd	0.04
Hauling 1/3 cu. yd. 1 mile	0.10
Total	$0.90

Kentucky Rock Asphalt.—The following data are from the Clarence Center Road, John D. Rust, engineer, collected during the season of 1910. In this work an 8-ton tandem roller was found to do better than a 6-ton tandem. The cost of handling, spreading, and rolling this material, from data of 5 days selected, varied from 3.3 to 3.6 cts. per sq. yd.; the average being 3.4 cts. The following may be taken as a typical analysis of this cost:

Abbreviations. L. Laborers.
F. Foreman.
T. Teams.
E. Roller engineer.

Asphalt $10.25 per ton f.o.b. unloading point.
Run of July 20, 1909.
9.22 tons hauled and placed.
,730 sq. yd. covered.
0 lb. asphalt per sq. yd.

L. at cars, 10 hr. at $1.50 each	$ 7.50
1/2 F. at cars at $2.25 per day	$ 1.12
T. haul 2 miles at $4 per team	20.00
L. on wheelbarrows, 11 hr., each 15 cts. per hour	8.25
T. at shredding machine	4.40
L. on rakes, 11 hr. at 15 cts. per hour	4.95
L. shoveling, 11 hr., at 15 cts. per hour	4.95
F. at shredder, 11 hr. at 22.5 cts. per hour	2.48
E. on roller, 11 hr. at 30 cts. per hour	3.30
Total	$56.95
Cost per square yard,	$0.033.

McClintock Cube Pavement.—The general costs of this experimental pavement were given in Chap. VI. We here give the detailed cost of the vitrified-clay cubes and clay-ash cubes only, as the concrete cubes have not worn satisfactorily.

Vitrified Shale Cubes.—During 1909, 74,000 2½" vitrifie shale cubes manufactured at Reynoldsville, Pa., were laid at a cos as follows:

Teams at 50 cts. per hour

74,000 cubes f.o.b. Reynoldsville	$231.25
Freight	68.41
Carting	67.00
Laying	20.00
Total	$386.66

NOTE.—331 sq. yd. were covered at a cost of $1.17 per squar yard.

Clay and Ash Cubes.—In 1910, cubes made of a local clay mixe with ashes and burned were tried in the effort to get a cheap tough clay product. As far as known, this is the first time brick made in this way have been used on roadwork.

The ash-clay process has been worked out and patented b Karl Langenbeck of Boston, Mass. Many local clays used fc ordinary brick or farm tile will not stand up under vitrificatio without the addition of expensive, imported refractory clays but the substitution of coal ashes for the more expensive clay has a similar effect and the cost is materially reduced. Some c the local clay was sent to Mr. Langenbeck, who turned out a fe cubes that compare favorably in toughness with the best pavin bricks on the market.

The Standard Sewer Pipe Company, of Rochester, N. Y., unde took to furnish 400,000 2" cubes of this description for Mr. M Clintock. It was necessary for them to experiment to determine practical method of molding, the correct temperature to use, an the best proportion of ashes, which naturally raised the price abov ordinary practice. In molding they used a modification of th ordinary pipe-molding machine, which produced a hollow square c cubes, at the rate of 30,000 cubes per hour. The scoring knive were so set that the cubes were nearly cut apart, leaving jus enough uncut clay to hold them together during the burnin after which a light blow separated them cleanly The toughnes of the resulting cubes can probably be increased by further exper ment; but the product was good, although not up to the standar of the sample cubes made by Mr. Langenbeck.

The cost of the ash-clay cubes was as follows:

400,000 cubes f.o.b. Rochester, N. Y.	$1200.00	$0.711 per sq. yc
Carting, 6 miles	247.75	0.147 per sq. yc
Filler	27.00	0.016 per sq. yc
Labor of laying	191.77	0.113 per sq. yc
Roller	12.94	0.008 per sq. yc
Total	$1679.46	$0.995 per sq. yc

NOTE.—1688 sq. yd. covered

Labor, 22 cts. an hour
Teams, 50 cts. an hour } for laying and carting.

Mr. McClintock has stated, in discussing the cost, that in large ıantities he believes the cubes can be delivered f.o.b. at the ant for $1.50 per 1,000, which would reduce the cost as shown ove to about 60 cts. per square yard, and that the high cost of ying was due to the irregular shape of the first batch, due to not oring the cubes deeply enough.

Amiesite Cost Data.—Road 1319, Honeoye Village, season of 15. H. W. Baker, engineer in charge. 4,700 sq. yd. laid 16′ de 2¾″ deep. Laid in two courses. Bottom course 2¼″ thick arse material; surface ½″ thick fine material.

Material:	
588 tons at $4 per ton f.o.b. plant	$2352.00
588 tons freight 54 cts. per ton	341.04
Total cost materials	$2693.04
Labor—force at cars unloading:	
6 laborers at $2 per day	$12.00
1 foreman at $2.50 per day	2.50
1 fireman at $3 per day	3.00
1 night fireman at $2.50 per day	2.50
	$20.00
Equipment at cars:	
1 boiler and pipe line per day	8.00
½ ton coal and oil	2.50
Total daily cost of unloading	$30.50
Hauling ¾ mile:	
4 teams at $5 per day	$20.00
Spreading and compacting:	
1 asphalt raker	3.00
4 laborers at $2 per day	8.00
1 rollerman	3.00
Per day	$14.00
Equipment:	
1 roller (10-ton tandem)	10.00
Coal, oil, etc	0.80
Daily cost spreading and compacting	$24.80
Summary daily force account:	
Unloading	30.50
Hauling	20.00
Spreading and compacting	24.80
	$75.30
Number of days worked, 15	
Total labor 15 days	$1129.50
Total materials cost	2693.04
Total cost	$3822.54
Cost per square yard	0.81
Bid price square yard	0.85

TABLE 220.—DEPTHS AND WEIGHTS OF AMIESITE
(Weights given are per square yard)

	Amiesite Loose	Weight Pounds	Amiesite Sq. Yds. Per Ton	Filler Loose	Weight Pounds	Filler Sq. Yds. per Ton	Total Depth Loose	Total Weight Pounds	Ultimate Compression	Square Yds. Per Ton
SANDSTONE	2¼″	153	13	1″	67¾	29.5	3¼″	220¾	2″	9.06
	2⅝″	178½	11.3	1″	67¾	29.5	3⅝″	246¼	2¼″	8.12
	3″	204	9.8	1″	67¾	29.5	4″	271¾	2½″	7.36
	3⅜″	229½	8.7	1″	67¾	29.5	4⅜″	297¼	2¾″	6.73
	3¾″	255	7.8	1″	67¾	29.5	4¾″	322¾	3″	6.2
TRAP ROCK	2¼″	168¾	11.8	1″	75	26.6	3¼″	243¾	2″	8.2
	2⅝″	196⅞	10.2	1″	75	26.6	3⅝″	271⅞	2¼″	7.36
	3″	225	8.9	1″	75	26.6	4″	300	2½″	6.66
	3⅜″	253⅛	7.9	1″	75	26.6	4⅜″	328⅛	2¾″	6.1
	3¾″	281¼	7.1	1″	75	26.6	4¾″	356¼	3″	5.6
LIMESTONE	2¼″	164¼	12.2	1″	73	27.4	3¼″	237¼	2″	8.43
	2⅝″	191⅝	10.4	1″	73	27.4	3⅝″	264⅝	2¼″	7.56
	3″	219	9.1	1″	73	27.4	4″	292	2½″	6.85
	3⅜″	246⅜	8.1	1″	73	27.4	4⅜″	319⅜	2¾″	6.26
	3¾″	273¾	7.3	1″	73	27.4	4¾″	346¾	3″	5.77

To find the amount of loose Amiesite necessary for any compressed thickness subtract ½″ from compressed thickness multiply by 1½ which equals loose thickness, to which add 1″ for filler.

To find what compressed thickness any given amount of loose Amiesite will give, subtrat 1″ from loose thickness, multiply by ⅔ and add ½″ for Filler.

Conditions:

This work was done under bad weather conditions the night temperature being below freezing and only 2 days with an air temperature above 55°F.

It was necessary to keep a night fireman at the cars to keep up steam and to move the steam pipes to different parts of the cars to insure the amiesite being in a condition to loosen and shovel in the morning. The material was loosened by bars and sledges to the bottom of the cars steamed 10 to 30 min. and then shoveled into dump wagons, covered with canvas and hauled to the street.

Under favorable weather conditions the cost of unloading from the cars would probably be reduced 40%.

Table of Amounts of Amiesite required for different thicknesses and materials, page 1186.

BITUMINOUS CONCRETE

Topeka Mix.—The following data on output and organization is quoted from *Engineering Contracting.*

The wearing surface mixture was prepared in a Cummer standard one-car portable paving plant of 2,000 sq. yd. of 2″ top per day (10 hr.) rated capacity, having a twin-pug mill (10 cu. ft.) capable of handling a 1,000-lb. batch of material. The total weight of this plant ready for transporting is 100 tons.

When the plant is working at its full capacity, 3 tons of coal are required per day.

The organization at the plant is as follows:

1 foreman.
1 engineer.
1 fireman and 1 blacksmith.
2 men at scales weighing materials.
2 men feeding stone to elevator to drier.
2 men feeding sand to elevator to drier.
2 men shoveling stone from car.
2 men shoveling sand from car.
2 men stripping barrels, etc.
1 man with horse, conveying sand from pile to elevator.
1 man with horse, conveying stone from car to elevator.

On a good day's work (8 hr.) the following quantities of material were used: 16 tons of asphalt, 132 tons of stone, 47 tons of sand, 11 tons of dust or filler, making a total of 206 tons of mixture.

FIELD COST DATA—BITUMINOUS MACADAM, MIXING METHOD. NEW YORK STATE RECONSTRUCTION, ASPHALTIC CONCRETE, 1925

E. A. Close, engineer in charge

General information

Length and Type.—Two miles of water-bound macadam, 2c years old, and 6.5 miles of bituminous macadam, 16 to 18 year old, was to be resurfaced and widened.

An evener course of black base (asphaltic concrete) was used tc fill pot holes, widen old macadam, and reduce excessive crown.

Top course was a modified Topeka mix or stone-filled shee asphalt.

Cross-section.—Black base course was 19′ top and 20′ botton width; 1½″ minimum thickness.

Top course was 18′ wide, 1½″ uniform thickness.

An edging of black base 6″ wide, 1½″ thick was placed on eacl side of the top course after side forms had been removed to protec the edges of top course. Cost of this edging is included in th black-base course.

Mix.—Black-base mix, in general, was proportioned 600 lb stone, 300 lb. sand, and 45 lb. asphalt.

Top-course mix, in general, was proportioned 265 lb. stone, 65 lb. sand, and 85 lb. asphalt.

Haul.—The average haul for all material was 6.2 miles fror plant to spread.

Progress.—55,833 sq. yd. top course were placed. 13,57 tons black base (including edging) were placed. Average sq. yd. and 0.4887 ton per linear foot road. Job 65% complete.

95 working days on black base. 38 working days on top course 38 days on repairs. Plant operated a total of 133 days on bot courses.

Distribution of General Charges.—Certain general charges show in Tables *A* and *B* could not be directly assigned to either course and are distributed in the proportion of the number of days plan time charged to each course, *viz.*, 95/133 to black base and 38/13 to top course.

Main office, financing charges, and other overhead figures wer not available and are not included.

TABLE OF GENERAL COSTS

Description	Quantity	Rate	Amount	Remarks
Salaries:				
Manager asphalt department	3.69 mo.	$500.	$1,845.00	Rate estimated
Office manager	$6\frac{11}{30}$ mo.	150.	955.00	
Rent:				
Storage space, office, etc	8 mo.	40.	320.00	Rate estimated
Office supplies:				
Telephone, postage, etc	8 mo.	25.	200.00	Rate estimated
General supplies:				
Coal	561.02 tons	3.40	1,907.47	
Coal	20 tons	4.50	90.00	Purchased locally
Fuel oil	39,000 gal.	0.045	1,755.00	Rate estimated
Lubricating oil and waste	....	....	200.00	Estimated
Truck covers, tarpalins	6	15.00	90.00	
General hauling:				
1½-ton truck	7⅓ mo.	375.00	2,750.00	Rate estimated including driver, gas, oil, repairs, tires, interest depression, etc.
Property damage:				
Residence property damaged by smoke and dust.	65% of $1500.00		975.00	Estimate including two new dust collectors, special oil burner, etc.

Insurance: Estimated 4% of pay roll $39,749.31	$1,589.97
Labor: See Table *A*	4,511.94
Equipment: See Table *B*	13,210.00
Total general charges	$30,399.38

TABLE *A*.—PLANT COSTS—LABOR
(Assembling, erecting, and repairing)

Title	Rate	Time	Amount	Remarks
Plant foreman..	$333.33 per month	81 days	$ 899.99	
Foremen.......	7.00 per day	76 days	532.00	
Crane operator.	225.00 per month	81 days	700.96	Rate estimated to include overtime
Mechanic......	7.00 per day	46 days	322.00	Rate estimated to include overtime
Raker.........	160.00 per month	1 month	160.00	
Tamper........	5.83 per day	4 days	23.32	
Fireman.......	5.00 per day	87 days	435.00	
Laborers.......	5.00 per day	100 days	500.00	
Mixerman......	40.00 per week	28 days	186.67	
Boilermakers...	12.00 per day	14 days	168.00	Rate estimated
Bricklayers.....	12.00 per day	2 days	24.00	Rate estimated
Rollermen......	40.00 per week	84 days	560.00	
Total........	....	....	$4511.94	Carry forward to Table of General costs

TABLE *B*.—PLANT COSTS—EQUIPMENT
(Interest, depreciation and repairs)

Equipment	Value	Interest	Depreciation	Repairs	Totals
Asphalt plant.........	$25,000[1]	Estimated at 40% of valuation		....	$10,000
Crane................	5,000[1]	$300	$ 800[1]	$200	1,300
Roller................	4,000[1]	240	500[1]	50	790
Small tools...........	2,000[1]	120	1,000[1]	....	1,120
Total—Carry Forward to Table of General Costs..				....	$13,210

[1] NOTE.—These figures were estimated.

TABLE OF TOP COURSE COSTS

Labor—mixing and hauling

Title	Rate	Time days	Amount	Totals
Plant foreman	$333.33 per month	38	$ 422.22	
Crane operator	225.00 per month	38	285.00	
Mechanic	7.00 per day	38	266.00	
Fireman	5.00 per day	59	295.00	
Mixerman	40.00 per week	38	253.33	
Laborers	0.50 per hour	122	610.00	
Watchmen	5.00 per day	38	190.00	
Trucks, 6-ton	30.00 per day	98	2,940.00	
				$ 5,261.55

Labor—spreading and compacting

	Rate per week	Time, days	Amount	Totals
Foreman	$40.00	15	$ 100.00	
Foreman	50.00	23	191.66	
Rakers	40.00	15	100.00	
Rakers	50.00	28	233.33	
Tamper	35.00[1]	14	81.67	
Tamper	40.00[1]	10	66.67	
Laborers	6.00	283	1,698.00	
Rollerman	45.00	38	285.00	
			$2,756.33	$ 2,756.33

(continued on next page.)

Materials (top course)

Material	Price	Quantity	Amount	Totals
Crushed stone	$ 2.01[1] per ton	1,153.567 tons	$2,318.67	
Sand	1.40 per cu. yd.	1,998.17 cu. yd.	2,797.44	
Portland cement	2.70 per bbl.[2]	60.00 bbl.	162.00	
Form lumber	42.00 per M. feet	0.994 M. ft. b. m.	39.65	
Form lumber	50.00 per M. feet	0.800 M. ft. b. m.	40.00	
Asphalt	0.069 per gal.[2]	85,988 gal.	5,933.17	
Delivery charge lumber	5.00	2	10.00	
				$11,300.93

Summary (top course)

Prorated from Table, page 1189, $^{88}/_{138}$ × $30,399.38	8,685.54
Mixing and hauling	$ 5,261.55
Spreading and compacting	2,756.34
Materials	11,300.93
General charges prorated	8,685.54
Total	$28,004.35

Unit costs

$28,004.35 ÷ 55,833 =	$0.5015 per square yard 1½″ thick
2 sq. yd. per linear foot of road, 2 × $0.5015	1.003 per lineal foot of road.
	6.50 per ton including asphalt

[1] This rate estimated.
[2] These prices estimated including delivery.

Table of Black Base Costs

Labor—mixing and hauling

Title	Rate	Time, days	Amount	Totals
Plant foreman......	$333.33 per month	97	$ 1,077.70	
Crane operator.....	225.00 per month	99	856.73	
Mechanic..........	7.00 per day	95	665.00	
Firemen...........	5.00 per day	191	955.00	
Mixerman..........	40.00 per week	95	633.33	
Laborers...........	.50 per hour	392	1,960.00	
Watchmen.........	5.00 per day	95	475.00	
Trucks, 6-ton.......	30.00 per day	337	10,110.00	
Foremen..........	7.00 per day	11	77.00	
				$16,809.83

Labor—spreading and compacting

Title	Rate	Time, days	Amount	Totals
Foreman...........	$ 40.00 per week	52	$ 346.67	
Foreman...........	50.00 per week	58	483.33	
Raker.............	40.00 per week	80	533.33	
Raker.............	50.00 per week	45	375.00	
Tamper...........	35.00 per week	79	460.83	
Laborers...........	6.00 per day	783	4,698.00	
Rollerman.........	45.00 per week	95	712.50	
				$7,609.66

Materials

Material	Price	Quantity	Amount	Totals
Crushed stone ..	$2.01 per ton	9,028.925 tons	$18,148.14	
Sand.....	1.40 per cu. yd.	3,209.48 cu. yd.	4,493.27	
Asphalt	0.069 per gal.	162,037 gal.	11,180.55	
				$33,821.96

General charges

Prorated from Table of General Costs, $^{95}/_{133}$ × $30,399.38 = $21,713.84

Total $79,955.29

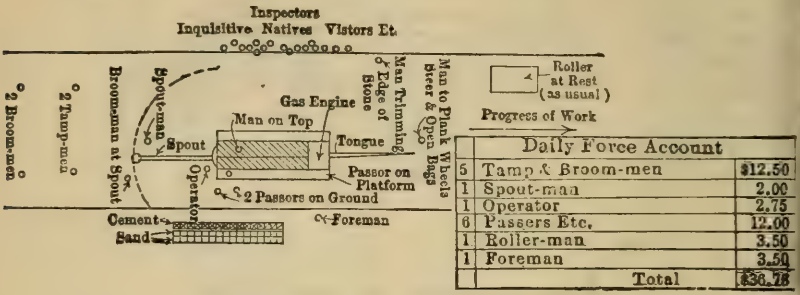
Unit costs

$79,955.29 ÷ 13,579 = $5.888 per ton.

0.4887 tons per linear foot of road $5.888 × 0.4887 = $2.877 per linear foot of road.

Note.—Prices and rates in top course table apply also to this table.

Hassam Concrete Pavement.—*Cost of Grouting.* Road 5529. Lyell Ave., Spencerport. Season 1915. E. E. Kidder, engineer in charge. Road 16′ wide 5″ deep compacted measure and approximately 6 miles long. 9880 cu. yd. of Hassam were grouted in 71 working days with the organization shown in the figure below.



	Daily Force Account	
5	Tamp & Broom-men	$12.50
1	Spout-man	2.00
1	Operator	2.75
6	Passers Etc.	12.00
1	Roller-man	3.50
1	Foreman	3.50
	Total	$36.75

71 days at $36.25 per day..........	$2573.75
Amount grouted....................	9880 cu. yd.
Cost of labor per cubic yard........	$0.26

Conditions.—Administration and superintendence good. Temper of crew rather bad as they were not receiving the wages that they expected to get for the first half of the job. Could have made a better record.

Speed of Work.—Averaged 450 lin. ft. per day.

Materials

Cement.—8500 bbl. used or an average of 0.86 bbl. per cu. yd of Hassam. This varied from 0.75 in the beginning to 0.95 during the latter part of the work when a liberal spread of stone was used to compensate for rough grading and a desire to end the work before winter.

Sand.—Royalty on sand was 30 cts. per load or 5.2 cts. per cu. yd of Hassam. Cost of haul corresponds to average costs given in previous cost data.

Stone.—16,050 tons of limestone 1¼″ to 3½″ in size were used This amounts to 3250 lb. per cubic yard compacted measure which is high for this grade of stone. This was due to a liberal use of stone over poorly shaped subgrade and to excess depth where wet material was removed.

Water.—Metered supply. 70 gal. per cubic yard of Hassam; this includes water for engines, leakage in a long line and considerable waste at the grout mixer.

CONCRETE ROADS

Cost Data.—Road 5423, Hartland Medina Part 2. Season 1914 F. W. Bristow, engineer in charge. 9550 cu. yd. 1 : 1½ : 3 concrete pavement laid 16′ wide 6″ deep.

Materials and Equipment

Cement.—Knickerbocker at $1.18 net bags returned f.o.b. siding. 1-mile average haul.

Sand.—Excellent local sand. 1¾-mile haul.

Stone.—Local crushed stone (Medina sandstone and granite ½″ to 2½″ in size) ¼-mile haul to crusher, 1-mile haul crusher to road.

Concrete Mixer.—Koehring with boom and bucket delivery ⅜ cu. yd. batch.

Speed of Work.—500 to 550 lin. ft. of road or 148 to 165 cu. yd. mixed and placed per 10-hr. day.

Actual Amount of Materials Used.

Cement 1.85 bbl. per cubic yard concrete.
Sand 0.4 cu. yd. per cubic yard concrete.
Stone 0.80 cu. yd. per cubic yard concrete.

Joints.

Wooden joints used for half the work.

Steel and felt joints used for half the work.

Labor Cost of Mixing and Placing Concrete.

Labor $1.75 per 10-hr. day.

The force at the mixer comprised:

1 foreman.
2 laborers setting forms.
10 laborers shoveling stone.
3 laborers shoveling sand.
6 laborers on stone wheelbarrows.
3 laborers on sand "
1 laborer passing cement.
1 laborer emptying cement.
1 mixer runner.
1 mixer fireman
4 laborers placing concrete.
2 laborers on screed.
2 laborers floating.
1 laborer preparing joints.
1 laborer sprinkling, brooming, etc.

The cost of setting forms, mixing, placing and finishing the concrete including coal ranged from 48 to 51 cts. per cu. yd.

This does not include overhead or plant charge.

The water cost per cubic yard concrete was approximately 4 cts. and includes laying pipe line and pumping from creeks.

The overhead charge per cubic yard of concrete was approximately as follows:

Bond	$0.036 per cu. yd.
Employers Compensation Insurance $2.92 per $100 payroll	0.096 per cu. yd.
Public Liability Insurance	0.016 per cu. yd.
Machinery and tools, freight hauling, erection, interest, depreciation and repairs	0.600 per cu. yd.
	$0.748
	Say $0.75 per cu. yd.

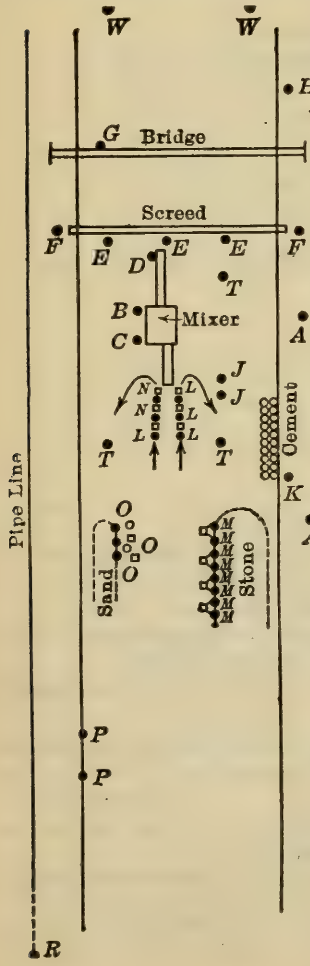
COST DATA, CONCRETE ROADS

Materials

Stone.—Cost of stone varied greatly during the year, from 62 to 85 cts. per cubic yard at the Blissville docks. To obtain a low voidage contractors ordered a mixture of No. 2 and No. 3 stone. This mixture weighed approximately 2700 lb. per cubic yard; therefore cost of stone f.o.b. car at destination would be:

1 cu. yd. stone at Blissville (say)	$0.8
Transfer (17 cts. per ton), 1.35 × 0.17	0.2
Freight (63 cts. per ton), 1.35 × 0.63 (rate to Patchogue)	0.8
Total	$1.8

Note.—Arrigoni paid $1.81 delivered f.o.b., on rate made in 1914 before stone raised. Freight rate to Patchogue then 60 cts.



Organization

Concrete 1-1½-3, 4 bag batch

Letter	Position	Number	Rate
A	Foreman	2	$3.00 & 4.00
B	Engineer	1	3.00
C	Fireman	1	2.50
D	Chute	1	2.00
E	Placing cone	3	2.00
F	Screeding	2	2.00
G	Floating	1	2.50
H	Brooming and general help	1	1.85
J	Cement (to hopper)	2	2.00
K	Cement (getting ready)	1	1.85
L	Stone (barrows)	4 or 5	1.85
M	Stone (shoveling)	8	1.85
N	Sand (barrows)	2 or 3	1.85
O	Sand (shoveling)	8	1.85
P	Forms	2	2.00
R	Pump	1	2.25
T	Trimming grade	3	1.85
W	Watchmen, covering and wetting down	2	1.85

Also charge ½ Supt. and ½ timekeeper

Trimmers "*T*" place expansion joints

Haul varied from 12 cts. per yd. mile using tractor roller and 5 cu. yd. trailers (3), to as high as 35 cts. per yd. mile with teams.

Transfer from cars to wagons 15 to 20 cts. per cubic yard dependent mostly on rate of wages; therefore, cost on job, with stone as per above, and a 2-mile haul would be approximately $1.88 + 0.60 + 0.20 = $2.68 per cubic yard.

Gravel.—Cost of same at bank, screened, and in bin varied from 15 to 85 cts. (dependent mostly on per cent of gravel). Haul same as stone.

Sand.—Cost of same at bank, (in wagons—screening unnecessary) varied from 35 to 60 cts.

Haul: 25 to 35 cts. per yd. mile.

NOTE.—When obtained from same pit as gravel I would consider its cost in bin as one-third the cost of all material leaving the plant, gravel in this case two-thirds of same total (say 25 cts. [sand] and 50 cts. [gravel] where gravel would be 75 cts. + were all sand wasted).

Cement.—Cost of cement varied greatly during the year; a good average was $1.20 per barrel net. Actual practice with graded stone has shown 1.75 bbl. per cubic yard of concrete a safe factor.

Haul varied from 3½ cts. (truck) to 5 cts. (wagon) per barrel mile.

Handling: average 2 cts. per bbl. when handled direct from car to job.

Plant.—Exclusive of forms and water line.

1 mixer—4-bag mix, 1:1½:3, at least 20 cu. ft. capacity
1 screed—19′ by 4″ by 12″, with ¼″ iron plate.
1 bridge—18′ × 3″ × 12″.
3 floats—(one split); and one trowel.
1 doz. forks—close tined for stone.
10 square shovels.
16 wheelbarrows (2 or 2¼ cu. ft. capacity)
1 canvas—160′ × 20′—with frame.
2 tampers.
1 template to test subgrade.
1 doz. pins to hold expansion joints (or special template for that purpose).
Small tools, other than noted.
1 Straightedge, 24′ × 10″ × 4″, for extra width on curves.

Total cost of above approximately $2300.

MANIPULATION

Exclusive of water, forms and trimming subgrade.

Superintendent (one-half)	$3.00
Timekeeper (one-third)	1.00
Foremen (2) (see Fig., p. 1196)	7.00
Engineer (1) (see Fig., p. 1196)	3.00
Fireman (1) (see Fig., p. 1196)	2.50
Mason (1) (see Fig., p. 1196)	2.50
Laborers (8 at 2.00) (see Fig., p. 1196)	16.00
Laborers (21 at 1.85) (see Fig., p. 1196)	38.85
Total	$73.85

Based on an average day's work of 182 cu. yd. (10-hr. day), the manipulation of a cubic yard of concrete would cost with the above organization, 40.6 cts.

NOTE.—The above organization has laid over 780 lin. ft. of 16½′ pavement (outside dimensions), in a 10-hr. day. (The 182 cu. yd. is based on a length of 600′ of pavement with a cross-section of 8.2 sq. ft.)

Water

Plant should be capable of supplying 30 gal. per minute. Pipe: 10,000 (at least) lin. ft. 2″ pipe, galvanized at 16 cts.... $1600.00
Black, at 14½ cts.... 1450.00
35 "Ts" for same (one each 300′) at 50 cts.... 17.50

Pumps: 3 to 25 hp., dependent on conditions. For lower power, gas engine O. K.; for higher, steam the best (latter, best for surety of supply).

Outfits $150 to $1000.

Where wells were necessary, 2″ supply pipe. Driving same $1.40 per foot for depths not greater than 40′; $1.50 to 70′ depth. This includes pipe and point.

Shaughnessy paid a lump sum for water from Bayshore to Islip ($300, I believe) from hydrants. On 5232A, water was bought from private parties for part of the work at $3 per day.

Cost of running steam pump located at well or surface water supply, including operator, varies from $5 to $8 per day dependent on weather conditions.

200′ of rubber hose at 34 cts. per foot necessary for connection with mixer and sprinkling road. Of this a 15′ section should be connected on intake pipe of mixer, with which to sprinkle subgrade

Forms

1. 6″ Channel forms (steel) 32 cts. per ft. including pins, 8′ sections.

2. Patent steel forms with bevel, 24 cts. per ft. Pins for same $1 each, one necessary for each section. Sections 12′ long.

3. Wooden forms with bevel about 12 cts. per linear foot.

Cost of placing same, 2 men at $2 per day, $4 per day (see P, Fig., p. 1196).

At least 1200′ of forms necessary, so that 600 lin. ft. of road can be built without forms being moved. Based on (2) forms would cost:

1200′ of forms....	$288.00
Say 110 pins....	110.00
Total....	$398.00

Subgrade

Three men generally necessary at $1.85 per day (see T, Fig., p. 1196).

General

A steam roller ($2200) might justly be, partially at least, charged to concrete. Cost of operating same, including rollerman, not greater than $12 per day if owned by contractor.

CONCRETE PAVEMENT COST DATA

Jame of Road, Main Street, Sec. III, County Highway 130, Erie County, New York State.

Length, 3.68 miles. Thickness, average 7″ parabolic crown.
Width, 16′. Proportions of mix, 1:1½:3.
Total cubic yards, 7038.

. Labor, exclusive of water supply, including supervision	$0.6818
. Plant forms and tools	0.3091
. Expansion joint material { steel plates 0.1782; tarred paper 0.0295; 0.2077 }	0.2077
. Water supply, including labor	0.0625
. Cement placed on roadside ready for mixer	2.3379
. Sand placed on roadside ready for mixer	0.8359
. Stone placed on roadside ready for mixer	1.0518
. Reinforcement, if any	0.0000
Total cost per cubic yard	$5.4867

abor, rate per hour, 16½ cts.; teams, rate per hour, 50 cts.; hours in day worked, 10.

Remarks: Work done by state day labor. Materials unloaded y hand. Plant charges included proportionate to life of plant. even-tenths mile average haul.

Jame of Road, Huntington-Amityville, Part 2, 1219, Suffolk County

Length, 4.69 miles. Thickness, 4¾″ and 6¾″ = av. 5¾″.
Width, 16′. Proportions of mix, 1:1½:3.
Total cubic yards, 7409.

. Labor, exclusive of water supply, including supervision	$0.52
. Plant forms and tools	0.58
. Expansion joint material	0.05
. Water supply, including labor	0.10
. Cement placed on roadside ready for mixer	2.36
. Sand placed on roadside ready for mixer	0.23
. Stone gravel placed on roadside ready for mixer	1.05
. Reinforcement, if any	0.00
Total per cubic yard	$4.89
Contractor's bid price	5.30

abor, rate per hour, 20 cts.; teams, rate per hour, 55 cts.; hours in day worked, 10.

Remarks: Auto truck for most of haul. Gravel furnished by ırge screening and washing plant accounts for high plant cost. 'nly proportionate part charged for this plant as it is to be used to roduce commercial output.

Road 1201—Nassau County Concrete Pavement

(1) *Sand:*	
In bins Heling Bros. per cubic yard	$0.15
Haul by auto (contractor owner) 2½ mi. at 15 cts.	0.38
Sand on road per cubic yard	0.53
Gravel:	
In bins Heling Bros. per cubic yard	0.85
Haul by auto (contractor owner) 2½ mi. at 15 cts.	0.38
Gravel on road per cubic yard	$1.23
Cement:	
Cement stored at $1 per day for 150 days	$150.00
Approximately 1170 bbl. stored. Storage per barrel	0.1
f.o.b. Farmingdale (estimate)	1.3
Handling and hauling (10 cts. estimate) double handling in most cases	0.1
Cement per barrel on road	$1.5
This price also approximate cost of cement bought from Parker, Hassam County.	
Plant:	
(2) 1 auto truck (Sauer)	$6,500.0
1 concrete mixer	1,200.0
2 doz. shovels	21.0
2 teams at $700, 2 bottom dumpers at $400	2,200.0
Forms (wooden) 800 lin. ft.	40.0
8 barrows	24.0
2 doz. picks	42.0
1 bucket conveyor, loader	600.0
1 screed	15.0
Incidentals	20.0
	$10,672.0
(3) Pressure water from fire plugs	
Pavement per cubic yard concrete 10 cts.	$100.0
1500 ft. (lin.) 2″ pipe at 8 cts.	120.0
100′ 2″ rubber hose	50.0
300′ 1″ rubber hose	45.0
	$315.0
(4) Manipulation per cubic yard in place. This does not include covering, uncovering, sprinkling	$0.9
(5) *Forms:*	
Setting and resetting forms per linear foot of road	$0.0

$$\frac{3 \times 1.75 \times 20 \text{ days}}{3093} = 0.03$$

(6) *Trimmings:*

Per cubic yard of concrete.................... $0.28

6 men at $ 1.75 20 days = $210
roller at 12.00 6 days = 72

$$\frac{\$282}{990} = 0.28$$

cubic yard of concrete

Expansion joints at 40 cts. apiece every 30′

Covering and uncovering and wetting concrete during curing season

2 men to cover at $1.75	$3.50	
2 men to uncover at $1.75	3.50	
1 man to sprinkle	1.75	
	$8.75	

$$\frac{8.75 \times 20}{990} = \$0.18 \text{ per cubic yard concrete}$$

Road No. 1203—Nassau County Concrete Pavement

(1) *Sand:*

In pit of Mr. Bennett per cubic yard	$0.15
Screening and loading (estimated)	0.22
Haul 2 mile (auto truck) contractor owner at 12 cts	0.24
Cost per cubic yard on road	$0.61

Trap rock (imported):

F.o.b. Baldwin $1.59 per cubic yard	$1.59
Unloading 15 cts	0.15
Haul 1.6 mile at 25 cts. teams and auto truck	0.40
Stone per cubic yard on road	$2.14

Cement:

F.o.b. Baldwin per barrel	$1.38
Handling and hauling per barrel 5 cts	0.05
Cement per barrel on road	$1.43

(2) *Plant:*

1 screed	$ 20.00
1 concrete mixer	1800.00
1 steam roller	3000.00
1 doz. wheelbarrows	36.00
2 doz. shovels	21.00
3 teams at $700, 3 bottom dumpers at $400	3300.00
1 auto truck	5000.00
2 doz. picks	42.00
Forms (wooden $20; steel $126)	146.00
Incidentals	50.00
Water wagon	400.00
	$13,815.00

Water:

Pressure line fire plugs, total	$100.oc
4000′ 2″ pipe 6 cts.	240.oc
100′ 2″ rubber hose	50.oc
300′ 1″ rubber hose	45.oc
	$435.oc

(4) *Manipulation:*

Includes all works, sprinkling, covering, uncovering, in place complete per cubic yard	$0.6

(5) *Forms:*

Setting and resetting forms per linear foot of road	0.0

(6) *Trimming* (Subgrade)

Per cubic yard concrete in place	0.2
Expansion joints at 40 cts. apiece every 30′	

Road No. 1219.—Suffolk County Concrete Pavement

(1) *Sand:*

In bins Heling Bros. pit cubic yard	$0.1
Haul by auto (contract) 1.5 miles estimate 30 cts.	0.3
Cost per cubic yard on road	$0.4

Gravel:

In bins Heling Bros. pit cubic yard	$0.7
Haul by auto (contract) estimated 30 cts.	0.3
Cost per cubic yard on road	$1.0

Cement:

Bbl. f.o.b. Farmingdale	$1.2
Handling and hauling	0.0
Cement on road per barrel	$1.3

(2) *Plant:*
Same as on 1218

(3) *Water:*

Cost of water	$700.c
1 mile 2″ pipe at 6 cts. per foot	320.c
100′ 2″ rubber hose	50.c
400′ 1″ rubber hose	60.c
1 pump and gas engine (estimate)	1000.c
	$2130.c

(4) *Manipulation:*

Includes all work; sprinkling, covering, uncovering, in place complete per cubic yard	$0.5

(5) Forms, setting and resetting per linear foot of road	0.c

(6) *Trimming:*

Per linear foot of road	0.c
Expansion joints at 40 cts. apiece every 30′.	

Road 1218—Suffolk County Concrete Pavement

(1) *Sand:*

In bins Heling Bros. pit cubic yard	$0.10
Haul by auto (by contract) 1.7 miles approximate	0.40
Sand per cubic yard on road	$0.50

Gravel:

In bins Heling Bros. pit cubic yard	$0.75
Haul by auto (by contract) approximately	0.40
Cost per cubic yard on road	$1.15

Cement:

F.o.b. Farmingdale	$1.27
Handling and hauling	0.08
Cement on road per barrel	$1.35

(2) *Plant:*

Gravel and sand screening complete, including various set ups	$15,000.00
1 concrete mixer	1,800.00
1 roller	2,800.00
1 screed	20.00
18 wheelbarrows	54.00
2 doz. shovels	21.00
3 teams at $700, 3 bottom dumpers at $400	3,300.00
2 doz. picks	42.00
1 road planer and scarifier	600.00
Forms (steel)	630.00
Tarpaulins	100.00
Incidentals	75.00
	$24,442.00

(3) *Water:*

Total paid for water approximately	$130.00
1 mile 2″ pipe at 6 cts	320.00
100′ 2″ rubber hose	50.00
400′ 1″ rubber hose	60.00
	$560.00

(4) *Manipulation:*

Includes all work, sprinkling, covering, uncovering, in place complete per cubic yard	$0.54

(5) *Forms:*

Setting and resetting form per lineal foot of road	0.02

(6) *Trimming:*

Per lineal foot of road	0.06

Expansion joints 40 cts. apiece every 30′.

COST DATA

Name of Road, Huntington Town Line-Farmingdale, Part 1, Suffolk County

Length, 1.27 miles. Thickness, 5″ and 7″ = Av. 6″.
Width, 16′. Proportions of mix, 1:1½:3.

Total cubic yards 2051.

1. Labor, exclusive of water supply, including supervision	$0.56
2. Plant forms and tools	0.61
3. Expansion joint material	0.06
4. Water supply, including labor	0.12
5. Cement, placed on roadside ready for mixer	2.13
6. Sand, placed on roadside ready for mixer	0.22
7. Stone, placed on roadside ready for mixer	1.01
8. Reinforcement, if any	0.00
Total per cubic yard	$4.71
Contractor's bid price	5.30

Labor, rate per hour, 20 cts.; teams, rate per hour, 55 cts.; hours in day worked 10.

Remarks: Auto truck for most of haul. Gravel furnished by large screening and washing plant accounts for high plant cost. Only proportionate part charged for this plant as it is to be used to produce commercial output.

Road 1202—Nassau County

(1) *Sand:*

Estimated at 10 cts. per cubic yard in bins	$0.10
Haul (by contract) estimated at 40 cts. per cubic yard	0.40
	$0.50

Gravel:

Stiff-leg derrick set up (in bins)	$2.00
Haul (by contract) estimated at 40 cts. per cubic yard.	0.40
First set up per cubic yard on road	$2.40
Drag line set up per cubic yard	$1.20
Haul (by contract) estimated 40 cts. per cubic yard.	0.40
Second set up per cubic yard on road	$1.60

Imported gravel per cubic yard scow Long Island City	0.85
Unloading from scow Long Island City	0.15
Freight Long Island City to Central Park	0.78
Unloading at Central Park	0.10
Haul (by contract) at 20 cts. per cubic yard	0.20
Cost per cubic yard on road	$2.08

Average cost per cubic yard on road $1.92.

Cement:

Bbl. f.o.b. Central Park estimated by market	$1.20
Haul by contract per barrel	0.06
Handling	0.02
Per barrel on road	$1.28
(2) *Plant* estimated	$12,000.00

(3) *Water:*

Cost of water	$1,000.00
4 mile 2″ pipe at 6 cts. per foot	1,270.00
100′ 2″ rubber hose at 50 cts	50.00
400′ 1″ rubber hose at 15 cts	60.00
1 pump, boiler, etc	1,000.00
	$3,380.00

(4) *Manipulation:*

Includes all work, sprinkling, covering and uncovering; in place complete per cubic yard $0.64

(5) *Forms:*

Setting and taking up per lineal foot of road 0.04

(6) *Trimming:*

Per lineal foot of road 0.075

Expansion joints at 40 cts. apiece every 30′.

COST DATA

Name of Road, Little Valley-Cattaraugus, Part 1, Cattaraugus County

Length, 5.35 miles. $\left\{\begin{array}{l}\text{3900 lineal feet 16′.}\\ \text{9700 lineal feet 14′.}\end{array}\right\}$

Thickness, $\left\{\begin{array}{l}6'' \text{ and } 8'' = \text{Av. } 7''.\\ 5\tfrac{1}{4}'' \text{ and } 7'' = \text{Av. } 6\tfrac{1}{8}''.\end{array}\right\}$

2.575 miles completed.

Width, 16 and 14. Proportions of mix. 1 : 1½ : 3.

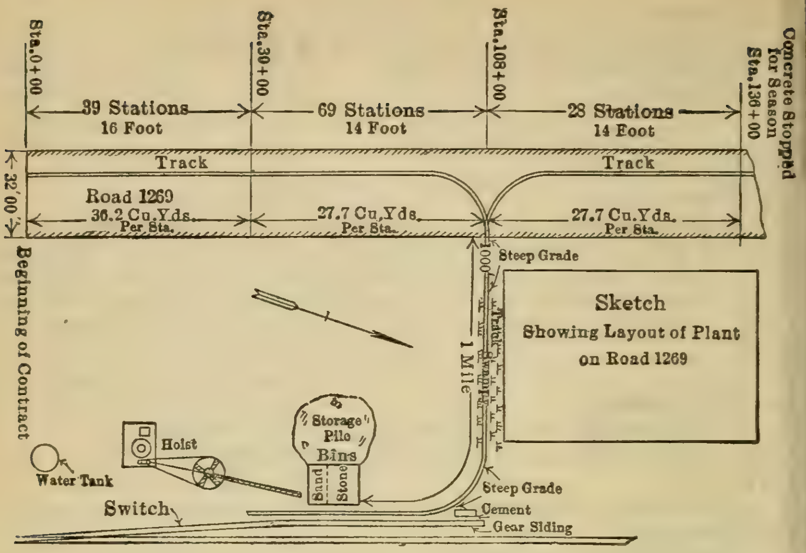
Total cubic yard 8280—This cost covers 4165 cu. yd.

1. Labor, exclusive of water supply, including supervision	$0.423
2. Plant forms and tools 66.2 + 15.8 cts. for coal	0.820
3. Expansion joint material	0.045
4. Water supply, including labor	0.030
5. Cement, placed on roadside ready for mixer	1.984
6. Sand, placed on roadside ready for mixer	0.522
7. Stone, placed on roadside ready for mixer	1.505
8. Reinforcement, if any	0000
Total cost per cubic yard	$5.324
Contractor's bid price	6.30

Labor, rate per hour, 18½ cts.; teams, rate per hour, none used; Hours in day worked, 10.

Remarks: Industrial railway plant delivering sand, stone, and cement into hopper of concrete mixer, clam-shell unloader used to take material off cars. Material delivered alongside mixer in buckets proportioned for one-batch size.

For plant layout see illustration.



Concrete Pavement Work.—Geneva-Dresden Road, New York State, season of 1925. Length 5.27 miles. 18′ width of pavement aid in two 9′ strips. 9,900 cu. yd. of concrete placed from July 1 to Sept. 2, 50 working days. Average output per day, 200 cu. yd. Average length of haul, switch to mixer, 1.5 miles.

Concrete Organization at Mixer:

Rex mixer (6-bag batch), $7000 initial cost.

1 operator at 75 cts. per hour	$ 7.50
2 derrick men at 40 cts.	8.00
1 foreman at $1	10.00
1 oiling forms at 40 cts.	4.00
2 placing reinforcement and joint at 40 cts.	8.00
4 men placing concrete at 45 cts.	18.00
2 men on screeds at 45 cts.	9.00
3 finishers	19.50
5 men setting forms at 40 cts.	20.00
Total labor	$104.00
20 gal. of gasoline for mixer ±	5.00
Oil for mixture, (approximately)	1.00
Total per day	$110.00
Cost per cubic yard	$ 0.55

Exclusive of overhead and equipment charge.
This cost does not include cover and curing.

Cement-concrete Pavement.—3900 Ft. of 6″ and 8″–16 Ft. and 9700 Ft. of 5¼″ and 7″–14 Ft.

Item	Amount	Amt. per Cu. Yd. Conc.	Amt. per Unit	Avg. Haul	Per Yd. Amount	Concrete		Haul		Unloading		Remarks
						Unload	Haul	Yd. Mi.	TonMi.	Yd.	Ton	
Cement (Net)	$8036.00	$1.930	$1.00 bbl.	1.95 mi.	1.93 bbl.	.023	.031					
Sand	1837.50	0.441	1.05 yd.	1.95 "	0.42 yd.	.035	.046	.0565	.043	.082	.063	
Stone	5547.04	1.332	1.23 ton	1.95 "	0.9 yds.	.074	.099					
Joints	187.95	0.045	0.028 ft.									Includes Setting Forms, Covering and Watering Conc.
Manipulation	1764.00	0.423										
Unloading	549.50	0.132										
Hauling	735.00	0.176										
Coal (240 ton)	660.00	0.158	2.75 per ton	(Assumed)								
Water	124.92	0.030										

$4.667 — Cost per Cu. Yd. Excluding Cost of Plant. (See Below)

PLANT

Hauling

Item	No.	Cost per	Amt.	
Dinkey Engines	3		2,500.00 Est.	Second Hand
Buckets	90	$6.50 each	585.00 Act'l	New (Wooden)
Track	20,000 ft.	0.26 ft.	5,200.00 "	Second Hand
Trucks	30	25.00 each	750.00 Est.	" "
Kopples	6	50.00 "	300.00 "	" "
			$9,335.00	

NOTE. Values attached to plant are estimated by Engineer where noted.

Unloading

Bins	1 Double	$1000.00 Est.	Pictures 1 and 2
Derrick and Hoist		1800.00 "	
		$2800.00	

Manipulation

Mixer (Austin Cube)	½ Yd.	$1900.00 New	Picture 5

Total Cost of Plant = $14,035.00

Lockport City, Market St. and Lake Ave. C.H. 1153

Length = 1.27 Miles
Width = 30′ — 47′

Asphalt Block Cost Data

Type: Asphalt Block
Medina Block

Date	Station–Station	Lineal Feet	Square Yards	Hours Fore.	Amount	Mortar Bed: Mixing: Eng.	Mixing: Labs.	Mixing: Amount	Bed-men	Placing and Striking: Labs.	Placing and Striking: Amount	Laying Block: Layers	Amount	Cutters	Amount	Cull	Amount	Carry	Amount	Sand Cover	Amount
Nov. 16	67+70 67+87.2	87.2	270 Flare	8	$5.00	8	10	$5.50	8	35	$13.75	16	$10.00	....	......	5	$1.25	35	$8.75	...	.....
" 17	65+42 67+70	228	760	8	5.00	8	24	9.00	8	64	21.00	16	10.00	24	$6.00	24	6.00	56	14.00	...	.....
" 18	61+82 65+42	360	1200	8	5.00	8	32	11.00	16	72	28.00	32	20.00	40	10.00	16	4.00	112	28.00	32	$8.00
" 19	60+97 61+82	85	284	8	5.00	2	8	2.76	4	14	6.00	10	6.25	10	2.50	2	.50	36	9.00	...	.....
		Olcott St.																			
" 20	57+85 60+97	312	1205	8	5.00	8	32	11.00	16	56	24.00	40	25.00	40	10.00	8	2.00	128	32.00	...	.....
" 21	53+95 57+85	390	1300	8	5.00	8	32	11.00	16	56	24.00	40	25.00	40	10.00	8	2.00	112	28.00	...	.....
		Clinton St.																			
" 22	51+60 53+95	235	1008	8	5.00	8	40	13.00	16	72	28.00	40	25.00	40	10.00	8	2.00	112	28.00	40	10.0,
" 23	47+25 51+60	435	1450	8	5.00	8	40	13.00	16	72	28.00	40	25.00	40	10.00	8	2.00	112	28.00	40	10.00
		Flare St.																			
" 24	44+75 47+25	315	1106	8	5.00	8	40	13.00	16	72	28.00	40	25.00	40	10.00	8	2.00	112	28.00	40	10.00
	35+00 35+65																				
" 25	31+60 35+00	340	1274	8	5.00	8	40	13.00	16	72	28.00	40	25.00	40	10.00	8	2.00	112	28.00	40	10.00
" 26	30+00 31+60	160	534	8	5.00	8	35	11.75	14	28	15.75	35	22.00	35	8.75	14	3.50	84	21.00	40	10.00
" 27	28+75 30+00	125	418	8	5.00	2½	12½	4.06	5	10	5.38	12½	7.81	12½	4.06	5	1.25	30	7.50	...	.....
		Adam St.																			

"	28	25+50	28+75	325	1192	8	5.00	8	40	13.00	16	32	18.00	40	25.00	40	10.00	16	4.00	96	24.12	40	10.00
"	29	24+15	25+50	135	450	8	5.00	4	20	6.50	8	48	17.00	16	10.00	20	5.00	8	2.00	48	12.00	80	20.00
"	30	21+55	24+15	260	870	8	5.00	8	32	11.00	8	24	11.00	16	10.00	40	10.00	...	.....	96	24.00	40	10.00
Dec.	1	20+36	21+55	119	471	8	5.00	8	48	15.00	6	12	6.75	12	7.50	24	6.00	...	.....	102	25.50	8	2.00
"	2	......	......	......	......	...	.....	...	...	......	...	...	......	...	......	...	......	...	.....	...	......	40	10.00
"	3	......	......	......	......	...	.....	...	...	......	...	...	......	...	......	...	......	...	.....	...	......	40	10.00
"	4	......	......	......	......	...	.....	...	...	......	...	...	......	...	......	...	......	...	.....	...	......	40	10.00
"	5	......	......	......	......	...	.....	...	...	......	...	...	......	...	......	...	......	...	.....	...	......	40	$10.00
					13776	128	80.00	112½	485½	163.57	189	443	302.63	445½	224.06	485½	122.31	138	34.50	1383	345.75	560	140.00

Total Cost
$1912.82

ASPHALT BLOCK
Engineer's Estimate

Block at Mfg. Plant, Lockport	= $0.96	sq. yd.
Haul ½ Mile	= 0.03	" "
Sand	= 0.02	" "
Cement	= 0.03	" "
On and off	= 0.04	" "
Lay and Roll	= 0.07	" "
Cushion	= 0.04	" "
	1.19	" "
Profit	= .18	" "
	1.37	" "
Use $1.40		

MORTAR BED { Mixing = 163.57 = $0.019 per sq. yd.; Paving = 302.63 = 0.022 " " " }

Total Bed = 0.041 " " "

Estimate Based on Cost Data C.H. 1153

Blocks F.O.B. Lockport (Boots)	= $0.90	per sq. yd.
On and off	= 0.04	" " "
Haul ½ Mile	= 0.03	" " "
Sand	= 0.03	" " "
Cement	= 0.05	" " "
Lay	= 0.10	" " "
Mortar Bed	= 0.04	" " "
Carr'd For'd	1.19	" " "

BLOCK { Carrying = 345.75 = $0.025 per sq. yd.; Laying = 724.06 = 0.053 " " "; Cutting = 122.31 = 0.009 " " "; Culling = 34.50 = 0.003 " " "; Sand = 140.00 = 0.010 " " " }

Total Cost = 0.100 " " "

Bro't For'd	$1.19	per sq. yd.
Profit 10% Material	.10	" " "
" 20% Labor	.04	" " "
	$1.33	" " "

Contract Price $1.37

Concrete Pavement Cost.—Road 1639, New York State, season of 1922. 3.25 miles laid. Average daily output 105 cu. yd. 2-bag batch mixer. Concrete pavement 16′ wide laid full width in one operation. 6″ uniform thickness.

Organization at Mixer:

	10-hr. Day
1 operator	$ 9.00
1 foreman	5.00
1 man tending skip	4.50
1 man oiling forms, etc.	4.50
3 men placing concrete and steel	18.00
2 men on screeds, roller and belt	10.00
1 finisher	7.00
Forms:	
2 men on forms (setting)	12.00
Removing and moving forward	4.00
Earth Cover and Sprinkling:	
Daily average	14.00
Total	$90.00
	=$0.86 per cu. yd

Exclusive of overhead and equipment charge.

Brick Cost Data on Country Roads.—The cost of brick pavement on country roads differs somewhat from similar work on city streets There are not many data available for this class of work, bu through the courtesy of William C. Perkins, First Assistan Engineer, New York State Department of Highways, the author i able to give some unusually reliable data obtained from 15 miles o brick paving averaging 14′ wide, built near Buffalo, N. Y., in 1910. Mr. Perkins' method of estimating, as given on page 1214 assumes that 20% profit on both materials and labor will take care of the plant and pay-roll charges and give a reasonable profit The method of estimating is different from that given on macadam roads. His results are good.

Excavation.—Where brick pavement is built on an ordinary unimproved country road, the excavation is of the same class and will cost the same as given for macadam roads.

Where pavements are built over macadam roads and the old surface must be cut into 2 or 3″ and reshaped, the excavation is much more expensive. For this class of work see page 1218 (scarifying and reshaping).

Labor Manipulation for Different Items of Brick Pavement Laid during 1910, in the Buffalo Residency.—These items figured from force accounts kept by the different engineers in charge of roads

Labor averaged 17.5 cts. per hour.

Concrete Base, 5″ thick (exclusive of edging).

Machine mixing, laying same in place, including labor of tamping, etc.

Road 2–R, Buffalo-Hamburg.......	$0.0853 per sq. yd.	
Road 128, Buffalo-Aurora.........	0.0991 per sq. yd.	(gravel concrete)
Road 863, Blasdell Village.........	0.1228 per sq. yd.	
Road 87, Main Street, Sec. 2.....	0.1129 per sq. yd.	(3″ base)
Road 862, Hamburg Village.......	0.0655 per sq. yd.	(28′ and 30′ wide)

The excessive cost on Blasdell Village due to a poor concrete mixer (gasoline) which was constantly breaking down.

On Main Street, Sec. 2, poor organization and too high priced men; also, lack of water, causing delays.

On Hamburg Village low price due to width of base 28′ and 30′, allowing work to progress faster.

On Road 69, Main Street, Sec. 1, edging and base were laid in one operation; gasoline mixer; plenty of water; cement, $1.12; sand $1.40; labor, $1.90 per day; stone, $1.12 per cubic yard; base 3″ thick; 8″ edgings; cost in place, including edging $4.696 per cu. yd., or 50.6 cts. per square yard, or 88.6 cts. per lineal foot of road.

Assumption.—If 9 cts. per square yard is assumed as an average cost for 16′ road (exclusive of edging) the manipulation would be 54.8 cts. per cubic yard.

If 6.55 cts. per square yard is assumed for street work (Hamburg Village), the manipulation would be 47.2 cts. per cubic yard.

Concrete Edging. 8″ thick.

Hand mixed; placing same, including erecting of forms, and removing same; tamping, placing steel, and all labor necessary.

Road 2-R, Buffalo-Hamburg,	$0.0730 per lineal foot of edging.
	0.0821 per square yard of pavement (road 16′ wide).
Road 128, Buffalo-Aurora...	0.0555 per lineal foot of 5″edging.
	0.0713 per square yard pavement (road 14′ wide).
Road 863, Blasdell Village...	0.0826 per lineal foot edging.
	0.0929 per square yard pavement (road 16′ wide).
Road 87, Main Street, Sec. 2	0.0748 per lineal foot edging.
	0.0842 per square yard pavement (road 16′ wide).

Concrete Curb.—On Road 862, Hamburg Village, concrete curb 6″ top, 10″ bottom, 15″ deep; hand mixed, exposed curbing, all including erection and removal of forms, 12.94 cts. per lineal foot.

Assumption.—If it is assumed that 8.2 cts. per square yard of paving is the cost of edging and 9 cts. per square yard cost of base, the total cost per square yard, 16′ road (including edging) would be 17.2 cts. per square yard, or the manipulation would be $1.238 per cubic yard.

If $0.073 per linear foot of 8″ edging 10½″ deep is assumed, the manipulation would be $3.379 per cubic yard of the edging in place. (This high cost due to forms, etc., and the small amount of concrete per linear foot.)

Sand Cushion.—Spreading sand, rolling, and making bed ready for work.

Road 2–R, Buffalo-Hamburg,	$0.0102 per square yard
Road 128, Buffalo-Aurora,	0.0082 per square yard
Road 863, Blasdell Village,	0.0187 per square yard
Road 87, Main St., Sec. 2,	0.0151 per square yard
Road 862, Hamburg Village,	0.0160 per square yard (28′ and 30′ wide)

On Main Street, Sec. 1, Road 69; sand, $1.40; labor, $1.90; cost per square yard 2″ thick, 8.38 cts., including material.

Assumption.—From the above I would assume 1.3 cts. per square yard as cost of preparing sand cushion.

Brick Pavement.—Laying brick, including all labor of handling from the piles, removing all culls, and the rolling of the brick.

Road 2–R, Buffalo-Hamburg,	$0.0611 per sq. yd.
Road 128, Buffalo-Aurora,	0.0544 per sq. yd.
Road 863, Blasdell Village,	0.0969 per sq. yd.
Road 87, Main St., Sec. 2,	0.0965 per sq. yd.
Road 862, Hamburg Village,	0.0700 per sq. yd. (28′ and 30′ wide)
Road 69, Main St., Sec. 1,	0.0983 per sq. yd.

Assumption.—I consider Blasdell and Main Street, Sec. 1 and Sec. 2, too high and the engineer claims that the force was cut up and wasted time.

I would assume 7 cts. per square yard as cost of laying brick, etc.

Grouting.—Necessary grouting to obtain flush joints, scoop method, including the placing of the protecting sand covering.

Road 2–R, Buffalo-Hamburg,	$0.0219 per sq. yd.
Road 128, Buffalo-Aurora,	0.0211 per sq. yd.
Road 863, Blasdell Village,	0.0322 per sq. yd.
Road 87, Main St., Sec. 2,	0.0321 per sq. yd.
Road 69, Main St., Sec. 1,	0.0285 per sq. yd.
Road 862, Hamburg Village,	0.0273 per sq. yd. (28′ and 30′ wide)

On Main St., Sec. 1, Road 69; sand, $1.40; cement, $1.12; labor, $1.90; actual cost 8.48 cts. per square yard, including materials.

Assumption.—From the above I would assume 2.8 cts. per square yard, as the cost of applying grout.

Expansion Joints.—Removing strips, cleaning joints, and pouring tar.

Road 2–R, Buffalo-Hamburg,	$0.0067 per linear foot of joint.
	0.0076 per square yard pavement (road 16′ wide).
Road 128, Buffalo-Aurora,	$0.0057 per linear foot of joint.
	0.0073 per square yard pavement (road 14′ wide).
Road 863, Blasdell Village,	$0.0115 per linear foot of joint.
	0.0129 per square yard pavement (road 16′ wide).

On Main Street, Sec. 1, Road 69, the expansion joints cost .96 cts. per linear foot, or 3.3 cts. per square yard (road 16′ wide), ncluding material, labor, etc.

Assumption.—From the above I would assume 0.75 ct. per quare yard as the cost of expansion joints.

Unloading.—Data for unloading not reliable.

Road 2–R Buffalo-Hamburg, 1.4 cts. per square yard.

Road 863, Hamburg Village,	Contract taken for $1.50 per 1000 brick; unloaded, haul ½ mile, and pile; this would be 6 cts. per square yard.
Road 69, Main St., Sec. 1...	1.9 cts. per square yard.

Assumption.—I would assume 2.8 cts. square yard as on and off.

Hauling.—No reliable data.

If 600 brick per load, $5 per day for teams, 10 loads per day, are llowed haul 1 mile costs 3.4 cts. per square yard.

Summary, Labor Cost of Brick Pavement.

Manipulation of Concrete

Pavement 16′ wide; edging 8″ × 10½″.

[1] Concrete base..........	$0.09 per sq. yd..	$0.648 per cu. yd.
Concrete edge..........	0.082 per sq. yd.	3.378 per cu. yd.
Concrete base and edging	$0.172 per sq. yd.	1.238 per cu. yd

Brick Work Labor

Preparing sand cushion................	$0.0130 per sq. yd.
Laying brick.........................	0.0700 per sq. yd.
Grouting.............................	0.0280 per sq. yd.
Expansion joints.....................	0.0075 per sq. yd.
On and off...........................	0.0280 per sq. yd.
Haul one mile........................	0.0340 per sq. yd.
Cost of labor.................	$0.1805 per sq. yd

Useful Data for Brick Roads.

6″ × 10½″ edging per linear foot of edging....	0.016203 cu. yd.
8″ × 10½″ edging per linear foot of edging....	0.021605 cu. yd.
5″ × 16′ concrete foundation per linear foot 16′ road..............................	0.24691 cu. yd.
2″ sand cushion loose per square yard.........	0.0555 cu. yd.

1 barrel of cement will grout 36 square yards of pavement.

1 barrel of paving pitch will fill 130 linear feet of joints 1″ wide.

Amount of Grout Required for Stone Block Paving.—For blocks similar to Medina sandstone blocks running about 26 to the square yard, Gillette states that 0.6 cu. ft. of joint filler is required per square yard of pavement with joints averaging ½″ wide. Second quality blocks with wider joints require proportionally more.

[1] Recent cost data indicates that 35 cts. per cubic yard is ample.

Amount of Grout Required for Some Block Paving.—For block similar to Medina sandstone blocks, running about 26 to the sq. yd Gillette states that 0.6 cu. ft. of joint filler is required per sq. yd of pavement with joints averaging ½″ wide. Second quality blocks with wider joints require proportionally more.

STANDARD ESTIMATE, BRICK SURFACING, EXCLUSIVE OF FOUNDATION

Materials.

	Per Sq. Yd
Cost of brick, f.o.b. unloading point	$
" " sand for sand cushion, on job	
" " " " grout, on job	
" " cement for grout, on job	
" " paving pitch for expansion joints, on job	

Labor and Teaming.

Unloading brick and piling along road	$0.035
Hauling brick per mile	0.040
Preparing sand cushion	0.020
Laying brick	0.070
Grouting	0.028
Expansion joints	0.007
Total	$ —
Add 20% profit	—
Estimate	$ —

SAMPLE—STANDARD ESTIMATE, BRICK PAVEMENT—WM. C. PERKINS

Brick: $22.50 per 1000 f.o.b. cars at Road siding, bricks lay 40 to the sq. yd.
Labor, $0.175 per hour, 10 hours.
Sand, 1.00 per cu. yd. on cars at siding.
Stone, 1.25 per cu. yd. on cars at siding.
Cement, 1.30 per bbl. delivered on work.

Sand:

f.o.b. cars	$1.00
Unloading	0.15
Haul 1 mile @ $0.30	0.30
Cost cu. yd. sand	$1.45

Stone:

f.o.b. cars	$1.25
Unloading	0.15
Haul 1 mile @ $0.30	0.30
Cost cu. yd. stone	$1.70

Concrete: 1 – 2½ – 5.
Use any standard mixing tables, stone 1″ and under, dust screened out.

Cement, 1.19 bbl. ...	×	$1.30	=	$1.55
Sand, 0.46 cu. yd. ...	×	1.45	=	0.67
Stone, 0.91 " " ...	×	1.70	=	1.55
*Manipulation			=	0.50
				$4.27
20% profit				0.85
Total				$5.12

The manipulation is based on machine-mixing and is for base alone laid 5″ thick. The concrete edging is estimated separately and runs from $0.13 to $0.15 per lin. ft.

Material per Square Yard

Brick f.o.b. cars	$0.900	
Sand cushion and cover	0.080	
Grout (sand and cement)	0.042	
Material expansion joint	0.008	
		$1.030

Labor per Square Yard

Unloading and piling	$0.035	
Haul 1 mile	0.040	
Laying and rolling	0.070	
Making sand cushion	0.020	
Grouting	0.028	
Expansion joints	0.007	
Culling, replacing, etc	0.005	0.205
		$1.235
20% profit		0.247
Total		$1.482

Therefore, standard 16′ road is estimated to cost, per square yard (exclusive of edging):

Concrete base	$0.711	
Brick	1.482	
Total	$2.193	per sq. yd.
Say,	$2.20	per sq. yd.

*Recent cost data indicates that $0.35 is ample with labor at $0.175 per hour.

INCIDENTAL ITEMS

Guard-rail Paint

15 lb. white lead } 1 gal. paint.
¾ gal. oil }

25 to 30 lb. white lead and 1½ gal. oil to paint 100 ft. guard rai 3 coats.

In Report of 1901 the Massachusetts Highway Commissior gives the following costs for repainting guard rail:

Lineal feet of guard rail painted	350,33(
Cost of paint per gallon (freight not included)	$ 1.05
Cost of paint per lineal foot of guard rail	0.008
Cost of paint and painting per lineal foot of guard rail	0.016
Lineal foot of guard rail painted per gal	134.4
Number gallons of paint used per lineal foot of guard rail	0.007
Time required to paint 1′, in decimals of an hour	0.026

Concrete Guard Rail.—Style of rail shown in sketch on page 681 chapter on Minor Points.

Labor, 22.5 cts. per hour.

Cost of manufacturing 1233 lin. ft. of rail of the above descrip tion. Taken from the Report of the New York Highway Com mission of 1910.

Lumber	$ 32.46	$0.026 per lin. foot
Steel	139.64	0.114 per lin. foot
Cement	57.62	0.046 per lin. foot
Gravel	10.00	0.008 per lin. foot
Metal cores	77.00	0.063 per lin. foot
Labor	231.83	0.188 per lin. foot
Miscellaneous	5.35	0.004 per lin. foot
Total	$553.90	$0.449

These data apply to small quantities; if manufactured on large scale the cost should be reduced to about 30 cts. per line foot.

The cost of setting the above rail varied from 9 to 12.5 cts. pe lineal foot: labor 22.5 cts. per hour. This does not include haulin from the factory to the intended position on the road.

Guard Rail.—In the following data the labor cost alone given, for the materials will vary so much at different times an places that any quotations would be of little value.

The style of rail erected is similar to sketch, page 676. Roa 715, 9760 lin. ft. were built at the following cost, according t S. O. Steere, engineer in charge: Post-hole auger diggers an ordinary shovels were used; the holes were dug in medium har clay; labor at 20 cts. per hour, foreman $3 per day; unskilled labc used in painting fence.

Digging post holes, setting posts, nailing on rails (erecting fenc complete):

Cost	$0.0428 per lineal foot
Painting three coats	0.0094 per lineal foot
Total for erecting and painting	$0.0522 per lineal foot

Road 5046, W. G. Harger, as engineer. 2448 lin. ft. Built by subcontractor, Max Weller.

Force: Max Weller acted as foreman. In these data he has been arbitrarily allowed salary of $4 per day........... $4.00
1 helper........................... 2.50
1 helper........................... 2.00
1 helper........................... 1.75
Cost of erecting and painting complete, per lineal foot 6.6 cts.

Concrete Shoulders and Slope Protection 1920
Road 1393A, Scottsville-rush

Concrete shoulders 12″ thick.
1:2½:5 mix (1-bag batch).
2 strips of concrete 3′ wide and 6′ wide.
⅓ cu. yd. per lineal foot.

men placing and finishing at	$5.50	$ 33.00
boom	5.00	5.50
drum	5.50	5.50
engineer	8.00	8.00
fireman	5.50	5.50
hopper	6.00	6.00
cement	6.00	12.00
sand (wheelers and shovelers)	5.50	11.00
stone (wheelers and shovelers)	5.50	33.00
forms	5.50	11.00
grading	5.50	11.00
foreman	8.00	8.00
	Labor total	$149.50
nterest, depreciation, and repairs on mixer allow		20.00
	Total	$170.00

80 cu. yd. placed on an average.
Cost per cubic yard for labor of placing $2.10.

Cobble Gutter.—Road 5046, W. G. Harger, engineer.
Labor, 17.5 cts. per hour. Foreman, $3.50 per day.

Cobbles averaged 6″ in size; no sand cushion required, as gutter was built in a sand cut. Gutter was laid by ordinary laborers using paver's tools; tamped with a paving rammer, and the top voids filled with No. 2 stone crushed on the job.

430 sq. yd. were laid at the following cost per square yard:

Cobbles, free	$0.000
Loading ⅙ cu. yd. of cobbles	0.030
Hauling ⅙ cu. yd. of cobbles ½ mile	0.024
Laying and tamping	0.080
Filler.—Cost of 0.05 cu. yd. No. 2 stone at crusher bin, approximately	0.030
Hauling 0.05 cu. yd. 1 mile	0.015
Spreading and brooming, 0.05 per cu. yd. No. 2 stone	0.010
Total	$0.189

PAVEMENT MAINTENANCE AND REPAIR COST DATA

Cost Data on Reshaping Road

Work was done on Main Street Road 69, Erie County, N. Y., between July 15 and Sept. 13, 1907.

The road had been built as a water-bound macadam. It was worn out, particularly in the center. There were few ruts, but the road was nearly level; in some stretches the center was lower than the sides. It was proposed to reshape the road and to lay a new top course treated with tarvia.

The work of reshaping was done by loosening the old surface with spiked wheels of roller; this separated the crust into chunks of various sizes which were broken up by men with picks. The stone was then raked from the sides to the center, brought to the required crown, and rolled ready for the new course of stone.

The cost of the complete operation included the number of men picking and the rollerman's salary.

Labor	$0.175 per hour
Rollerman	0.300 per hour

The roller was rented at a flat rate of $5 per day, and a portion of the time it was used on other parts of the work. This cost plus the coal and oil is not included.

The data were compiled daily, and as the work was performed practically every working day between the dates named an average of the square yard price should be nearly correct. The highest cost on any one day was 6 cts. per square yard, the lowest cost 1.6 cts. and the general average 3 cts. per square yard.

Through the courtesy of Halbert P. Gillette,[1] author of "Handbook of Cost Data," the following is published:

Cost of Resurfacing Old Limestone Macadam.—"In *Engineering News*, June 6, 1901, I gave the following data to show that the intermittent method of repairing macadam is the most economic. The data were taken from my timebooks and can be relied upon as being well within the probable cost of similar work done by contract under a good foreman. It will be noted that the cost of operating the roller is estimated at $10 per day. This includes interest and depreciation as well as fuel and engineman's wages.

"The road was worn unevenly, but as it still had sufficient metal left, very little new metal was added.

"The roller used was a 12-ton Buffalo Pitts, provided with steel picks on the rear wheels. It required 80 hours of rolling with the picks in to break up the crust of a surface 19,400 sq. yd. in area, 240 sq. yd. being loosened per hour. The crust was exceedingly hard, and, at times, the picks rode the surface without sinking in, so that a lighter roller would probably have been far less efficient. In fact, a 10-ton roller had been used a few years previous for the same purpose at more than double the expense per square yard, I am told. The picks simply open up cracks in the crust to a depth

[1] Gillette's Handbook of Cost Data, Myron C. Clark Publishing Company, edition of 1907, page 147. Pages 288 and 289, edition of 1910, in slightly different form.

of about 4", and it is necessary to follow the roller with a gang of laborers using hand picks to complete the loosening process. The labor of loosening and spreading anew the metal was 1.880 man hours, or a trifle more than 10 sq. yd., per man hour. About 60 % of this time was spent in picking and 40% in respreading with shovels and potato hooks.

"After the material had been respread, the short section was drenched with a sprinkling cart, water being put on in such abundance that when the roller came upon the metal the screenings which had settled at the bottom in the spreading process were floated up into the interstices. The roller and sprinkling cart were engaged only 63 hrs. in this process, 300 sq. yd. being rolled per hour; an exceptionally fast rate. The rapidity of rolling was due to four factors: (1) the great abundance of water used, the water being a very short haul; (2) the unyielding foundation (telford) beneath; (3) the abundance of screenings and fine dust, the road not having been swept for some time; (4) the great weight of the roller, which was run at a high rate of speed. I am not prepared to say that longer rolling would not have secured a harder surface, but I doubt very much whether it would. The metal, I should add, was hard limestone. Summing up, we have the cost of resurfacing the road per square yard to have been as follows:

	Cents per Square Yard
Picking with roller at $1 per hour	0.40
Picking by hand labor at 20 cts. per hour	1.20
Respreading by hand labor at 20 cts. per hour	0.80
Rolling with roller at $1 per hour	0.33
Sprinkling with cart at 40 cts. per hour	0.13
Foreman, 143 hours at 30 cts. for 19,400 sq. yd.	0.44
Total	3.30

"At this rate a macadam road 16' wide can be resurfaced for a little more than $300 per mile. The frequency with which such resurfacing is necessary will, of course, depend upon several factors, chief of which are the amount of traffic and the quality of the road metal. I should say that 5 years would not be far from the average for a country road built of hard limestone. Unless the road has had an excess of metal used in its construction, new metal should be added at the time of resurfacing to replace that worn out.

"I am unable to see how any system of continuous repair with its puttering work here and there can be as economical as work done in the manner above described. I would not be understood, however, as favoring an entire neglect of the road between repair periods. At times of heavy rains and snows, ditches and culverts need attention and there should be some one whose duty it is to look after such matters. What I do question is the economy of having a man continuously at work putting in patches upon the road."

Recapping.—The cost of recapping with any style of macadam is practically the same as original construction for that style of work except the item of scarifying and reshaping the old road.

COST DATA SURFACE TREATMENT

It will be noted in the following table that the tendency of surface oiling practice is to each year reduce the amount of oil and cover used. This is in line with the data set forth in the chapter on Maintenance.

Hot-tar Flush Coats.—The cost of applying hot-tar flush coats by hand is practically the same as given for applying bituminous-binder penetration method. See page 1169.

The cost of machine application is given on page 1170.

Calcium Chloride.—The cost of applying calcium chloride as a temporary dust layer on ten miles of road in Monroe County, New York, as given by Frank Bristow, First Assistant Engineer, New York State Department of Highways, is as follows:

The material was applied by an ordinary agricultural drill. The force used was, 1 horse and driver, 30 cts. per hour; 1 helper, 20 cts per hour. No preliminary work of sweeping was done; the material was spread on the middle 12′ of macadam, using approximately 0.7 lb. to the square yard, the average speed being 0.5 miles, or 350 sq. yd., per day, at a cost of 0.15 cts. per sq. yd.

Cost of calcium chloride at plant......	$13.00	net ton
Freight.............................	1.60	per ton
Unloading from cars, approximately...	0.15	per ton
Hauling 3 miles, approximately......	0.90	per ton
Total, delivered on road........	$15.65	per ton
Total per square yard delivered on road	0.0059	
Labor of spreading..................	0.0015	
Total per square yard in place..	$ 0.0074	
Total per mile 12′ wide, approximately.............		$52.00

Cost of Applying Calcium Chloride

Road 5507 Scottsville—Canawagus. Season 1915. W. G. Harger engineer in charge.

15 tons were applied at the rate of 1½ lb. per square yard on a 16 road for $22 or at the rate of $1.50 per ton.

Force used: 1 team hauling agricultural plaster spreader. laborers helping driver. Calcium chloride in metal drums had been previously distributed along the road.

Wages: Team, $5 per day; laborers, $2 per day

MAINTENANCE AND REPAIR COSTS

Cold Oiling.—The following data is furnished by Mr. Frank Bristow, Supt. of Repairs, Division No. 5, New York State Department of Highways. The work was done in 1910. Labor averaged $0.20 per hour; teams, $0.50 per hour.

Oiling. Actual Cost Data.—No. 6 stock or 65% asphaltic base oils applied cold by Studebaker Oiler upon macadam road which

ad been swept by horse sweeper, oil being broomed by hand where ecessary and then covered by a thin coat of dustless screenings, r gravel, spread by hand.

The labor costs include pumping oil from the car tank, hauling ame to road, applying same, sweeping road and spreading screenngs; also, demurrage on cars and moving tools and repairs, but ot cost of the plant.

TABLE 221

County			Average cost of materials		Average Quantities of Materials Used		Average Cost	
	No. Jobs Average	Average Haul, Miles	Oil per Gal. on siding	Cover per Cu. Yd. Along Road	Gallons per Sq. Yd.	C. Y. Cover per Sq. Yd.	Labor per Sq. Yd.	Total Labor and Material per Sq, Yd,
)rleans	7	2.48	$0.0435	$1.82	0.42	0.016	$0.013	$0.057
Niagara	4	2.24	0.0425	1.57	0.43	0.016	0.014	0.057
Erie	12	2.00	0.0437	1.88	0.34	0.012	0.007	0.045
Erie	3	4.43	0.0455	1.83	0.42	0.015	0.019	0.066

Other information would show that cost per mile to sweep average oad is $8.33; cost per gallon applying oil 0.75 cts.; cost all labor weeping, hauling, applying oil and cover about 25 cts. per gallon sed.

TABLE 221*A*.—DIVISION 7 NEW YORK STATE DEPARTMENT OF HIGHWAYS.

H. G. HOTCHKISS, SUPERINTENDENT OF MAINTENANCE

Cost data for oiling, surface treatment 1915

Miles	No. Sq. Yds.	Kind Bit. Mat.	Gals. per Sq. Yd.	No. Tons of Cover per Mile	Total Cost per Sq. Yd.	Total Av. Cost per Sq. Yd.	Cost per Mile 16′ Surface
20.54	158144	C. O.	0.25	62	0.0344	0.026	244.06
23.63	188208	C. O.	0.25	41	0.0250		
17.75	146734	C. O.	0.24	37	0.0237		
19.94	172775	C. O.	0.19	43	0.0189		
21.47	200995	C. O.	0.19	59	0.0264		
16.22	199925	C. O.	0.28	74	0.0287		
22.51	188601	L. C. O.	0.20	31	0.0195	0.0183	171.78
41.09	382330	L. C. O.	0.20	27	0.0177		
15.44	126657	H. C. T.	0.25	40	0.0323	0.0330	309.77
13.42	126056	H. C. T.	0.25	40	0.0337		
17.19	143846	L. C T.	0.25	47	0.0319	0.0319	299.45

TABLE 221*B*.—DIVISION 7 NEW YORK STATE DEPARTMENT OF HIGHWAYS

Cost data repainting and rebuilding guard rail 1914

No. Lin. Ft. Painted One Coat	Cost per Lin. Ft.	No. Lin. Ft. Painted Two Coats	Cost per Lin. Ft.
15325	$0.0212	26428	$0.0425
79925	0.0233	8433	0.0360
17486	0.0251	12824	0.0352
42027	0.0264	13160	0.0442
Rebuilding Wooden Guard Rail		Rebuilding Concrete Guard Rail	
No. Lin. Ft.	Cost per Ft.	No. Lin. Ft.	Cost per Ft.
160	0.219	100	$0.896
554	0.189	335	0.764
360	0.200		
272	0.141		

COST DATA SURFACE TREATMENT WITH OIL AND TAR

New York State Department of Highways Division No. 7

	Year	Miles	Total Number Gallons Used	Total Average Cost per Mile	Total Average Cost per Sq. Yd.	Cover Lb. per Sq. Yd.	Cover Cost per Sq. Yd.	Bit. Mat. Gal. per Sq. Yd.
Cold Application	CONTRACT WORK							
	1916	148.96	52,717 Tar 35,389 L.H.O. 159,228 L.C.O.	$221.77	$0.0252	8	$0.0065	0.19
	1915	229.21	236,827 C.O. 114,186 L.C.O. 99,140 Tar	217.37	0.025	10	0.0101	0.25
	1914	188.96	225,533 C.O. 201,583 Tar	404.36	0.047	18	0.0218	0.26
	DEPARTMENTAL FORCE ACCOUNT							
	1916	47.21	84,294 Tar 7,164 L.C.O.	$192.84	$0.022	8	$0.0039	0.22
	1915	57.10	23,358 C.O. 17,081 L.C.O. 54,099 Tar	284.79	0.034	12	0.0113	0.23
	1914	53.73	112,690 Tar 29,796 C.O.	409.32	0.048	18	0.0220	0.28
	1913	13.49	33,955 Tar	601.12	0.072	28	0.0244	0.30

Hot Application	Contract Work							
	1915	7.37	17,560 Tar	$521.67	$0.074	28	$0.0263	0.29
	1914	13.87	15,362 Tar 24,720 H.O.	817.80	0.102	61	0.0538	0.36
	Departmental Force Account							
	1915	4.51	13,131 H.O.	$ 812.94	$0.114	39	$0.0444	0.41
	1914	1.00	4,693 H.O.	1,413.21	0.150	58	0.0710	0.50
	1913	8.75	31,119 H.O.	1,222.18	0.138	51	0.0529	0.40
No Cover	Contract Work							
	1915	1.96	3,674 L.C.O.	$112.64	$0.012			0.20
	1914	0.50	1,173 C.O.	224.00	0.024			0.25
	1913	2.26	4,243 C.O.	150.45	0.016			0.20

Cost of Bituminous Material per Gallon							Cost of Labor per Hour		
Year	Tar, Cold Application	Tar, Hot Application	Light Hot Oil 65–75 % Asph.	Light Cold Oil 40–55 % Asph.	Cold Oil 50–65 % Asph.	Hot Oil 85–95 % Asph.	Year	Labor Cents	Teams Cents
1916	$0.0592	$	$0.057	$0.051	$	$	1916	20–30	50–62½
1915	0.058–0.066	0.1025		0.031	0.032	0.059	1915	15–25	50–62½
1914	0.066–0.096	0.093			0.034–0.076	0.0777	1914	15–25	50–62½
1913	0.075					0.1125	1913	15–25	50–62½

TABLE SHOWING CHARACTER OF MAINTENANCE AND RENEWAL EXPENDITURE FOR 1914, OVER 500 MILES OF ROAD

DIVISION 7

NEW YORK STATE COMMISSION OF HIGHWAYS

Perry Filkins, Division Engineer — MAINTENANCE DEPARTMENT REPORT 1914 — H. G. Hotchkiss, Jr., Acting Superintendent of Maintenance

County	Miles	Resurfacing		Oiling		Patrol	Maint. Mat.	Extra Labor	Guard Rail	Miscel.	Eng. and Insp.	Total
		Miles	Cost	Miles	Cost							
Genesee.........	31.90	3.00	$9470.50	24.74	$6419.63	$2574.00	$310.86	$910.44	$451.55	$161.67	$2072.13	$22370.78
Ontario.........	100.99	5.59	40068.03	52.38	19399.66	7311.00	4167.60	7921.50	1713.78	286.96	3930.98	84799.51
Orleans.........	58.14	3.47	13482.82	36.02	15796.64	4629.00	2337.01	1388.86	460.34	94.26	4537.10	42726.03
Livingston	82.05			41.19	16392.56	6753.00	2044.05	557.83	1441.77	334.00	3550.66	31073.87
Monroe.........	220.19	4.75	68062.19	100.36	50682.88	14331.00	13317.54	9683.57	3702.02	986.57	9534.42	170300.19
Wyoming........	21.36			4.00	2423.60	1866.00	811.77	1573.51	581.85	70.73	1358.40	8685.86
Total...........	514.63	16.81	$131083.54	258.69	$111114.97	$37464.00	$22988.83	$22035.71	$8351.31	$1934.19	$24983.69	$359956.24

Average cost per mile oiling..$429.52
Average cost per mile resurfacing..7797.95
The items of maintenance material and extra labor Monroe Co. includes 5.75
Average cost per mile patrol.. 73.00
Number feet guard rail painted one coat.. 154763
Number feet guard rail painted two coats.. 60845
Number feet wooden guard rail rebuilt.. 1426
Number feet concrete guard rail rebuilt.. 2196

Engineering and inspection.......... 6.94%

Miles calcium chloride average cost per mile..........................$185.23
Average cost per foot...............$0.0240
Average cost per foot............... 0.0403
Average cost per foot............... 0.19
Average cost per foot............... 0.85

CULVERT AND BRIDGE COST DATA

Culverts

The following data will help in estimating the cost of small concrete jobs, such as culverts, walls, etc. This data was collected by Mr. E. E. Kidder during the season of 1908.

COST DATA SMALL CULVERTS

	Per Cu. Yd.
Forms (labor)	$0.58
Lumber	0.50
[1]Labor, mixing, and placing	1.18
[1]Foreman	0.20
[1]Broken stone, at crusher	0.90
[1]Hauling stone, one mile	0.30
Sand at pit at 65 cts. per cu. yd.	0.32
Hauling sand six miles	0.75
[1]Taking down forms	0.10
Cement at culverts	2.00
Total	$6.83

Labor, $0.15 per hour.
Concrete, hand-mixed.
200 cu. yd., placed in small culverts, averaging 12 to 15 cu yd. each.

NOTE.—The labor of placing the concrete is customarily sublet t masons for $2.00 per cu. yd.

Small Culverts

Java Center Road. George A. Wellman, Engineer.

One hundred and sixty-one cu. yd. of concrete in culverts averaging 12 to 20 cu. yd. each.

Boulders were embedded in the third-class concrete. Wate only had to be hauled for 30 cu. yd. of concrete.

Item	Total Quality	Materials: Unit Cost	Materials: Total Cost	Amt. per Cu. Yd of concrete: Material	Amt. per Cu. Yd of concrete: Cost
Cement	138 bbl.	$1.12	$154.56	0.86 bbl.	$0.9
[1]Sand	60 cu. yd.	1.00	60.00	0.37 cu. yd.	0.3
Crushed stone	130 " "	1.55	201.50	0.80 " "	1.2
Lumber	3 M	30.00	90.00		0.5
				Total	$3.1

Costs are f.o.b. unloading point; teaming of material include in the labor cost given below, except for sand, which cost $1.0 delivered on the job. Concrete mixed and placed by hand.

[1] Items accurate; other items approximately correct.

Cost of Labor and Teaming

Item	Total	Per Cu. Yd. of Concrete
Foreman	$93.00	$0.58
Labor, unloading stone from cars	20.00	0.12
Mixing, placing concrete, and removing forms	204.00	1.27
Carpenters, building forms	75.00	0.47
Teaming	182.00	1.13
Total Labor		$3.57
Total Material		3.13
Total		$6.70

Labor	$0.175	per hour
Teams	0.50	" "
Carpenters	0.25	" "
Foreman	0.30	" "

Small Span Concrete Arch.—The following information of cost of 19-ft. span concrete arch was given by Mr. Charles M. Edwards, First Assistant Engineer, New York State Department of Highways. Arch was built at Pembroke, N. Y., by a contractor who was crushing stone at a quarry about one-half mile from the work. Cement was hauled three-quarters of a mile. For the concrete a mixture of one part Portland cement, two parts sand, and four parts stone was used. The old masonry abutments and wings were left in place and faced with 8 inches of concrete held by dowels. The quantities were: Concrete, 120 cu. yd.; steel bars, 4500 lb.; pipe railing, 200 lin. feet. The cost of the work was as follows:

Lumber, including arch centers	$156.00	on job
Steel	106.00	" "
Cement	137.00	on siding, f.o.b.
Stone	240.00	on job
Dust and sand	90.00	
Railing	78.00	f.o.b. siding
Labor	300.00	
Total	$1107.00	

Omitting the cost of railing this figure gives a cost of $8.57 per cu. yd. of concrete, including steel. This cost does not include salvage of lumber or overhead expenses of any kind. The contractor received $1500.00 for the work, including the earth filling, for which he used quarry strippings. This filling cost about $50.00.

[1] The sand on this job cost practically nothing but we have placed the cost at $1.00 in order to avoid a misleading item.

Cost Data (1924 Cost Conditions) Lock-joint Cast-iron Pipe

Approximate cost f.o.b. switch North eastern States:

Diameter	Per Foot
12″	$2.45
14″	2.65
16″	3.26
18″	3.67
20″	4.89
24″	6.52
30″	8.97

Averaging cost hauling and installing exclusive of trench excavation.

Diameter	Per Foot
12″	$0.10
16″	0.15
18″	0.20
24″	0.25
30″	0.30
36″	0.35

Profit item from 20 to 60 cts. per foot.

Bridge Foundation Excavation

Road 191. Season of 1926 (Hinman)

Common labor rate 50 cts. per hour.

400 cu. yd. foundation pit excavation in gravelly loam soil taken out by hand, rock, pick, shovel, bars and wheeled out of pit with wheelbarrows for $2.70 per cubic yard exclusive of overhead charges.

Pile Driving

Hinman (1926)

Road 191, New York State.—2000 lin. ft. piles driven by 1800-lb. drop hammer, steam hoist rig. Average penetration 1″ per blow; piles 25′ long in leads. Average cutoff 4′. Cost to drive $1.50 per foot of pile ordered in leads including all overhead charges, 1926 cost conditions. Poorly equipped and poorly managed job.

Average cost of suitable timber piles in this locality delivered on work 40 cts. per linear foot for piles less than 30′ total length.

Ordinary bid prices for small bridges in Western New York, 80 cts. to $1.20 per linear foot of timber piles.

Cost Data on Bridge 1 R.C. 1493 H-188
(45′ span steel I-beam bridge with concrete jack arch floor)

Item No. and unit used	Method and equipment used	Labor cost per unit	Material cost-unit	Wage
Rock excavation				
No. 3. Cu. yd. Hard shale	Steam shovel used for 60 % of exc. Bal. by teams and slip scrapers.	\$1.53 per cu. yd.	\$0.29 per cu. yd. dynamite	\$0.45 per hr.
No. 2. Earth exc. cu. yd.	Steam shovel, teams, wagons, and scrapers used.	\$0.38 per cu. yd.	....	\$0.45 per hr.
No. 21. 2nd class concrete, cu. yd.	1 bag mixer, wheelbarrows, chutes, etc. ½ bag mixer used on footing	\$0.38 per cu. yd.	Gravel \$0.71 + F½H Sand \$0.55 + F½H	\$0.45 per hr.
Abutment concrete				
Forms for above item	Local labor used. Hemlock ½ in. matched. Whalers 2 ft. centers. Wired 3 ft. vertical	\$1.13 per cu. yd. \$0.13 per sq. ft.	Lumber, wire, nails \$0.77 per cu. yd. \$0.09 per sq ft.	\$0.50
No. 16. 1st cl. concrete for structures	1 bag mixer used. Concrete wheeled into forms.	\$2.62 per cu. yd.	Sand \$0.42 per cu. yd. Stone \$0.42 per cu. yd. Total \$2.11 per cu. yd.	\$0.60
Floor concrete				
Forms for above item	Imported labor. ½ in. matched hemlock	\$2.84 per cu. yd.	Lumber, wire, nails \$5.13 per cu. yd.[5]	\$0.60
No. 32A. Bar reinforcement for structures, unit lb.	....	\$0.021 per lb.	\$0.032 F.O.B.	\$0.60
No. 32B. Structural steel	Placed by bars, jacks, and staging.	\$0.32 per lb.	\$0.032 F.O.B.	\$0.60
No. 60A. Bit. waterproofing, sq. ft.	Heated over open fire. Poured from pails and broomed.	\$0.23 per sq. ft.		
No. 51D. Cement concrete pavt., cu. yd.	Poured with 1 bag mixer. Wheeled both ways.	\$3.60 per cu. yd.		

Cost Data on Bridge 1 R.C. 1493 H-188—*Continued*

Item No. and unit used	Overhead included, equipment per unit	Supt.	Misc.	Total	Source
Rock excavation					
No. 3. Cu. yd. Hard shale..........	$0.25 per cu. yd.	$0.15 per cu. yd.	$0.19[1]	$2.41	
No. 2. Earth exc., cu. yd...........	$0.202 per cu. yd.	$0.54 per cu. yd.	$0.207[2]	$0.843	
No. 21. 2nd class concrete, cu. yd.... Abutment concrete	$0.257 per yd.	$.025 per cu. yd.	$4.28[3]	$9.828	
Forms for above item..............	....	....	....	$1.92 cu. yd. $0.22 sq. ft.	
No. 16. 1st cl. concrete for structures. Floor concrete	$0.46 per cu. yd.	$0.83	$7.17[4]	$21.62	
Forms for above item..............	....	....	....	$7.97 cu. yd.	
No. 32A. Bar reinforcement for structures, unit lb....................	$0.0008 per lb.	$0.004	$0.068 per lb.	$0.065 per lb.	
No. 32B. Structural steel...........	$0.0008 per lb.	....	$0.002[6] per lb.	$0.0378 plus freight	
No. 60A. Bit. waterproofing, sq. ft....					
No. 51D. Cement concrete pavt., cu. yd[7]...........................					

[1] Teams $0.80 per hr. Shovel $3.80 per hr. Dynamite $17.50 per case.
[2] Trucks $2.50 per hr. Teams $0.80 per hr.
[3] Includes freight, hauling material, rubbing wall. Cement factor 1.29.
[4] Includes freight, hauling. Cement factor 1.77.
[5] Includes arches. 20 gauge corrugated metal.
[6] Hauling and freight on expansion plates.
Cement factor 2.13.

Cost Data Bridge Maintenance

Steel Bridges.

Paint every 2 to 4 years depending on moisture and gas contions.

Cost of painting (1923):

Labor $2.50 per ton per coat.
Paint 80 cts. to $1.30 per ton of steel per coat.

ee also p. 1235 for more detail data.)

Life of Steel Bridges.

Well maintained, 50 years or more.
Poorly maintained, 20 years or less.

Floors.

Life of plank	5 years average.
Life of concrete	8 to 15 years.
Life of bituminous concrete	8 to 15 years.

Reflooring Barge Canal Bridges (1925) Western New York

Lumber, $60 per M ft. b.m.
Carpenter work, $20 per M ft. b.m.
Total per M ft. new floor, $80.
Floors last about 5 years.

NOTE.—Where floors are strengthened by adding extra timber stringers, ps and bracing, carpenter work will run from $30 to $40 per M ft. B.M.

Dismantling Old Steel Bridge Superstructures, $10 per ton when ld as junk. $35 per ton old pin connected trusses to be reerected.

Amount of Paint Required on Flat Surfaces

Large variations in amount due to porosity of surface kind of int and expertness of painter. For average conditions 1 gallon paint should cover approximately 200 sq. ft. with two coats of int.

Pay-roll and Material Accounts

Page 1234 shows largest weekly pay rolls for 2 months' duration, ant values, and speeds of work for fourteen macadam roads in ew York State built in 1914. At the present time these pay rolls uld be two to three times as much and the equipment approxitely as shown on pages 1261 to 1264.

From these data and others such as general contractors' associan published data, it is reasonable to assume that a contractor s tied up, outside of money on plant and materials, from $10,000 $25,000 for the full length of time the work is in progress and for ort periods as high as $30,000 to $60,000 for the ordinary rural vement job (5-mile length, 1926 cost conditions).

If cost of materials and freight increase, there may be the necesy of banking accommodations up to approximately $100,000 a short time on 5-mile concrete pavement jobs and up to ,000 on 5-mile macadam jobs.

(text continued on page 1238.)

New York State Barge Canal Division 4

Painting bridges, season 1925 (force account) (highway bridges steel cleaned bare steel 1 coat of red lead 1 finish coat black pain

Bridge	Cost	Notes	Total	Remarks
Hulberton Lift Bridge 191. Labor.......... Material.......	 $ 761.00 118.55	Cost left bridge averages $1500 per bridge $10.00 per ton. Engineer's estimate $7.00 per ton with 1 finish coat $10.00 per ton with 2 finish coats	$ 879.55	Poor condition 25% steel bare 140 tons steel $6.30 per ton
Holley Lift Bridge 187. Labor.......... Material.......	 $ 903.00 130.63		1033.63	Bad condition 40% steel bare 102 tons steel $10 per ton
Middleport Lift Bridge 216. Labor.......... Material.......	 $1846.00 255.86		2101.86	Bad condition 60% steel bare 214 tons steel $10 per ton
Albion Lift Bridge 199. Labor.......... Material.......	 $2,259.44 238.83		2498.27	Bad condition 70% steel bare 110 tons steel $22 per ton
Albion Lift Bridge 200. Labor.......... Material.......	 $ 903.00 205.45		1108.45	Bad condition 40% steel bare 107 tons $23 per ton
Spier's Bridge 170. Labor.......... Material.......	 $ 385.00 34.32	Cost fixed-truss bridges $770 per bridge $7.70 per ton. Engineer's estimate $7.30 per ton 1 finish coat $10.50 per ton 2 finish coats	419.32	Fair condition 15% steel bare 60 tons $7 per ton
Mitchell's Bridge 136. Labor.......... Material.......	 $ 242.00 41.25		283.25	Bad condition 30% steel bar 52 tons $5.50 per ton
Lyell Road Bridge 166. Labor.......... Material.......	 $ 123.00 26.08		149.08	Bad condition 40% steel bar 53 tons $2.80 per ton
Buffalo Road Bridge 165. Labor.......... Material.......	 $ 383.00 29.22		412.22	Bad condition 50% steel bar 58 tons $7.10 per ton
Clinton Ave. Bridge 144. Labor.......... Material.......	 $ 584.00 137.24		721.24	Poor conditio 25% steel bar 75 tons $9.60 per ton
Winton Road Bridge 143. Labor.......... Material.......	 $ 344.00 16.45		360.45	Poor conditio 25% bare 75 tons $4.80 per ton
Lee Road Bridge 169 Labor.......... Material.......	 $ 422.00 49.42		471.42	Bad condition 40% steel bar 85 tons $5.50 per ton

Pine Street Bridge, Lockport, 232. Labor.......... $3051.50 Material....... 451.52		3503.02	Bad condition 65% steel bare 400 tons $8.80 per ton
Lake Avenue Bridge, Lockport, 228. Labor.......... $ 1161.00 Material....... 184.26		1345.26	Poor condition 30% steel bare 80 tons $16.70 per ton
Brooks Avenue Bridge, 161. Labor.......... $ 72.50		72.50	Fair condition 10% steel bare 100 tons 70 cts. per ton
Bushnells Basin Guard Gate. Labor.......... $ 395.50 Material....... 117.64		513.14	Bad condition 50% steel bare 110 tons $5 per ton
Cartersville Guard Gate. Labor.......... $ 403.00 Material....... 83.55		486.55	Bad condition 50% steel bare 110 tons $4.70 per ton
East Guard Lock. Labor.......... $ 585.25 Material....... 157.67		742.92	Bad condition 50% bare 110 tons $7.30 per ton
West Guard Lock. Labor.......... $ 558.00 Material....... 169.87	Guard gate averages $550 per gate $5.00 per ton Engineer's estimate $7.00 per ton with 1 finish coat	727.87	Bad condition 50% bare 110 tons $7.20 per ton
Spencerport Guard Gate. Labor.......... $ 499.00 Material....... 56.91		555.91	
Iolley Guard Gate. Labor.......... $ 264.00 Material....... 65.16		329.16	
Gantry Crane, Pittsford. Labor.......... $ 155.00 Material....... 8.25		163.25	
Total amount labor and material		$18,878.32	

TABLE 222.—SPEED OF WORK, VALUE OF PLANT, FORCE ACCOUNT. SUMMARY OF PLANTS AND FORCE ACCOUNTS

Road No.	Style of Road	Local or Imported Stone	Kind of Hauling	Weekly Force Account	Value of Plant	Speed of Work Miles per Month
1	16-ft. Bit. Mac.	Imported	Mechanical and teams	$1,000	$13,500	0.7
2	16 " " " ...	"	Mechanical	800	13,600	0.7
3	16 " " "	"	Teams	900	8,000	0.5
4	16 " " " ...	"	"	1,000	8,000	0.6
5	16 " " "	"	"	—	4,500	0.4
6	16 " " "	" top (local bot.)	"	1,900	14,500	1.3
7	16 " " "	Local	Teams and Mechanical	600	12,000	0.5
8	16 " " "	"	Teams	1,000	9,000	0.5
9	16 " " "	"	"	600	9,000	0.6
10	16 " Water Mac ..	"	"	1,600	10,000	1.2
11	16 " " " ...	"	"	1,000	10,500	0.8
12	16 " " " ...	Imported	"	1,000	6,000	0.7
13	14 " " " ...	"	"	1,200	12,600	0.7
14	16 Resurfacing	"		500	5,000	1.5

Labor, 16 to 20 cts. per hour. Average 17.5 cts. Teams, 40 to 50 cts. per hour. Average 45 cts.

Note.—To accompany text page 1231.

DIVISION 4.—BARGE CANAL STRUCTURES—PAINTING SUMMARY
Recommended 1924 work. Force account work

Structure	Condition	Total number	Total tons	Estimate total cost	Estimate cost per ton	Labor and materials						
						Cleaning	Red-lead coat on exposed metal		First finish coat, gray		Second finish coat, black	
						Labor, man-days	Labor, man-days	Paint, gallons	Labor, man-days	Paint, gallons	Labor, man-days	Paint, gallons
Fixed bridges....	Bad	24	1,600	$19,000	$11.80	750	410	400	750	640	690	480
Fixed bridges....	Poor	13	850	8,000	9.40	250	140	140	390	330	360	250
Lift bridges.....	Bad	4	500	5,000	10.00	200	90	100	200	200	180	150
Lift bridges.....	Poor	3	450	4,000	9.00	100	50	50	180	180	160	130
Guard gates.....	Bad	8	900	9,000	10.00	320	200	200	400	360	330	270
Totals........	...	..	4,300	$45,000	$10.50 Av.	1,620	890	890	1,920	1,710	1,720	1,280

REQUISITION SUMMARY—1924 WORK

Total labor.................................. 6200 man-days
Total red-lead paint........................ 900 gal.
Total graphite paint (2 coats).............. 3000 gal.

NOTE.—Cost estimate based on labor at $6 per day,

Red-lead paint............. $2.70 per gallon { 14 lb. red lead; 0.7 gal. linseed oil.
Graphite bridge paint....... 2.00 per gallon

Quantity estimate: 0.5 gal. red lead per ton actually painted.
0.4 gal. per ton first coat graphite paint.
0.3 gal. per ton second coat graphite paint.
2 to 3 tons painted or scraped per man-day.

DIVISION 4.—*Continued*

Recommended 1925 work. Force account work

Structure	Condition	Total number	Total tons	Estimate total cost	Estimate cost per ton
Fixed bridges	Fair	21	1,400	$12,100	$9
Lift bridges	Fair	1	100	900	9
Totals	......	22	1,500	$13,000	

The following bridges (indicated by number) and guard gates are included in the painting estimate which accompanies.

Structures marked "Bad" have 35 to 60% of steel surface exposed to weather and should be painted in 1924.

Structures marked "Poor" have 20 to 35% of steel surface exposed to weather, and also should be painted in 1924 because their deterioration is manifestly progressive.

Structures marked "Fair" have 0 to 20% of steel surface exposed and likewise should be painted but may go over until 1925.

Fixed bridges			Lift bridges			Guard gates
Bad 1924	Poor 1924	Fair 1925	Bad 1924	Poor 1924	Fair 1925	Bad 1924
130	126	124	187	191	206	Cartersville
131	129	127	199	203		Bushnell's Basin
133	143	141	200	211		South Greece
134	144	142	216			West River
136	185	159				East River
137	186	161				Middleport
138	189	163				Medina
140	198	170				Albion
165	217	172				
166	219	173				
169	224	183				
171	226	193				
175	228	196				
176		197				
177		201				
179		202				
180		205				
184		209				
212		218				
213		223				
214		225				
215						
220						
221						

For the purposes of engineering estimates of cost, interest ‹
banking accommodations can be figured for the prevailing intere
rate for this kind of accommodation on the basis of $50,000 f
6 months for 18′ width of concrete pavement jobs 5 miles long aı
$40,000 for 18′ width of macadams, pavement 5 miles long whi‹
amounts to approximately $300 to $400 per mile for interest on p:
roll, freight, and materials.

Bonds and Liability Insurance.—There is considerable fluctu
tion in the rates for these items of cost, and the engineer shou
use the prevailing rates for his territory and class of work bei:
done. The different types of bond and liability insurance a
described briefly. The prevailing rates for rural pavement wo
in New York in 1926 are as follows:

Performance bond................	0.5% to 2.0% of contract pri
Compensation-insurance (labor)...	4 to 5% of pay r
Public liability....................	1%± of pay r
Automobile liability on trucks.....	$40 per Ford truck per ye

The cost estimates in this chapter are based on allowing 10%
pay-roll cost for bonds, insurance, etc.

BONDS

Bonds are divided into three general classes: fidelity, judic
and surety.

A fidelity bond guarantees the honesty of persons.

A judicial bond guarantees the honesty and performance of le;
obligations.

A surety bond guarantees the performance of an agreement
contract.

Each of the above divisions covers a number of subdivisions a
classifications.

If all highway work, either construction or maintenance, touch
upon from other viewpoints in this book, were performed by c‹
tract, there would be no need of mentioning any form of bond l
the surety, but because in the past few years certain political sı
divisions, such as counties and towns, have developed their o
construction and maintenance forces, thereby performing the w‹
directly and under the supervision of elected or appointed office
a short description of all types of bonds with their approxim:
costs is included.

Fidelity Bonds

Fidelity. *Individuals.*—This type of bond covers the execut:
officers of corporations, assistant executive officers, manag
and superintendent of stores, buildings and industrial operatio
bookkeepers, cashiers, clerks, salesmen, officers and members
organizations, associations (fraternal, beneficial, labor, et‹
building loan associations, cooperative companies.

Schedule.—Where six or more persons are to be covered, a
where the surety amounts to $20,000 or over, a schedule bond m
be issued. This form may be used in connection with ban

large mercantile establishments, industrial operations, associations of all kinds (fraternal, beneficial, or otherwise). Special rates cover each classification.

Position Form.—This bond is a form that covers the position and does not name the person.

Bankers' Blanket.—This is a special form for banks, investment houses, stock brokers, etc. and is issued in lump sum. It protects the bank not only from dishonesty but from other hazards such as holdup, robbery, burglary, mysterious disappearance, etc. The rates are based upon the amount of insurance, number of employees, form of bond etc., and the cost of such a bond is purely individual and based on all circumstances connected with its issue.

Judicial Bonds

All court bonds such as administrators, guardians, committees, receivers in bankruptcy, trustees and also release of attachment, replevin, stay of execution or any bond given to court to guarantee payment before undertaking penalty or obligation in connection with court action, indemnity to sheriff, or other public officers.

Surety Bonds

Construction, supply, maintenance, proposal or bid bonds, etc.

Miscellaneous Bonds

Freight charges, indemnity bonds, lease bonds, lien bonds, replacement bonds, lost securities, etc.

Depository Bonds

Banks, government, state, county, city, and other municipalities.

License Bonds

Government, state, city, town, and village. Bonds required by various cities, towns, and villages for use of streets, construction of vaults, employment agencies, detective agencies, explosives, gasoline tanks, boxing clubs, etc.

Federal Bonds

Various forms required by the United States Government such as prohibition, use of intoxicating liquors, manufacturing of non-alcoholic beverages, warehouse bonds, custom house bonds covering foreign shipments, immigrant bonds, etc.

Except for surety bonds covering construction contracts in Class *A* and Class *B* hereinafter defined in New York State and also for New York City, the other types of bonds mentioned above are subject to a considerable variation in cost, and therefore general statements as to rates and premiums are confined to the surety bonds to Class *A* and Class *B* types, commonly known as contract bonds and defined as follows.

Contract Bond Rates.—Contract bonds may be divided into general classes of construction *A* and *B*; supply; proposal; maintenance; construction and maintenance; supply and maintenance; paving; bridge building; dredging; indemnity bonds; lease bonds;

lien bonds; replacement bonds; city contract bonds; timber cutting bonds; U. S. Mail bonds; printing and engraving bonds.

Construction Class *A* covers all contracts wherein the material, machinery, or device is to be installed, and the work on the premises covers merely the installation of the plant or machinery, such as automatic telephone exchange equipment, coal storage and coal handling machinery, furnishing and installing building elevators, machinery made to special order or design; refrigeration plants on land; signal towers on railroads, standpipes and water towers; quarrying and furnishing of stone for buildings, breakwaters, etc. or for the incorporation of stone in buildings.

The rate for Class *A* construction contracts as above outlined, covering all public contracts in New York City which may be let by all departments of the state government including the state architect, the department of public works, the conservation commission, the various state park commissions and to include public work for counties, cities, towns, villages, school districts and boards of education where the form of contract and bond does *not* make the surety liable to a direct action for the contractor's indebtedness for labor and material is one-half of 1% per annum on the contract price.

Construction Class *B* covers general contracts such as filtration plants; buildings; dams; water works; sewage-disposal plants; barge canals; breakwaters; foundations; locks; masonry; piers; highway construction, etc.

The rate for Class *B* construction contracts as above outlined for above contracts under the supervision of the same political and departmental subdivisions given above is 1% of the contract price for any period up to 24 months. Annual renewal thereafter is one-half of 1% of the contract price.

As an exception to above, the New York State architect's form of bond takes a rate of $20 per thousand on amount of contract for term of 2 years which includes 1 year's maintenance. Renewal premium at the rate of $10 per thousand per annum.

New York State Barge Canal contracts take a rate of $15 per thousand on the amount of contract for term of 2 years. The labor bond is included without extra charge.

Paving contracts for incorporated villages and cities take a rate of $10 per thousand per annum on the amount of contract.

Maintenance on same is $2 per thousand per annum on the value of work guaranteed.

In New York City contracts, all departments of the New York City government including all boroughs, boards, and commissions, except the Board of Transportation, take the following rates: Construction contracts Class *A* one-half of 1% per annum on the contract price. Construction contracts Class *B* 1% of the contract price for any period up to 24 months, and annual renewal thereafter one-half of 1% of the contract price.

Bridge contracts take the same rate as Class *B* construction, but separate contracts for steel and iron tonnage only, for reflooring and repairing superstructure only, and for including assembly or erection take the rate of $7.50 per thousand on contract price.

Separate contracts for furnishing and delivering metal superstructure only, without assembly or erection, are at the rate of \$2.50 per thousand on contract price.

Dredging contracts, for river and harbor work for the United States Government, tidewater dredging, and dredging on the Great Lakes carry a flat premium of \$7.50 per thousand on amount of contract.

Drainage ditches and all inland dredging or ditching done with a floating or power dredge carry a flat premium of 1½% on the contract price.

In bid or proposal bonds, the rate for construction contracts not exceeding \$2500 is 20 cts. per hundred on price bid; minimum premium \$1. For construction contracts of \$2500 or more, rate of bid or proposal bond is \$5 each.

Where no corporate surety bond has been required for either supply or construction contract, maintenance bonds covering material already supplied or work already completed carry a rate of three-fourths of 1% per annum for the amount of penalty on bond. Minimum premium is \$7.50 for term.

The regular construction rate is charged for performance and maintenance. Rate begins immediately upon completion.

Indemnity Bonds

For bonds to indemnify public officials for payment of retaining percentages on completed construction work, where payment is otherwise delayed, the rate is 1% on amount of bond for its full term.

Lien Bonds

Separate bond not guaranteeing completion but guaranteeing owner, lender, mortgagee, or lessee against any liens being filed on building or improvement, where bond is given before the commencement of construction or improvement, or near the commencement of such work, and where at the date of bond no liens have been filed, carry a rate of \$10 per thousand on amount of bond for its term.

Where bond is given at or after completion of work, or when work is so advanced that only final payment remains to be paid and at date of bond no liens have been filed, the rate is \$5 per thousand on amount of bond.

Bonds given to release mechanics or material men's liens, lien of judgment, or any other liens which have been filed against building or other improvement are classified as court bonds, and the rate is \$10 per thousand per annum on amount of bond.

SIDEWALK BONDS

Classified as Construction

Sidewalk bonds are for performance of contract, either to municipality or private parties. The rates are as follows:

Performance \$7.50 per thousand on contract price.

Maintenance 1.50 per thousand on contract price per annum.

One year maintenance only, no charge.

Over 1 year maintenance, premium covers every year of maintenance including the first year.

WORKMEN'S COMPENSATION INSURANCE

Coverage.—Workmen's Compensation Insurance covers the obligation imposed by law upon the employer for compensation or damages for personal injuries to an employee arising out of and in the course of his employment; also the obligation assumed by an employer to pay to injured employees or their dependents the benefits provided under the Workmen's Compensation Law.

The Workmen's Compensation policy also covers liability imposed upon an employer for injuries sustained by employees by reason of the negligence of the employer when such injuries are not compensatory under any workmen's compensation law. This also includes payment of medical, doctor, and hospital bills.

Rates.—Rates for different classes of operation may be found in the Workmen's Compensation manual, which gives a complete general classification of all labor. Each class has a different rate per hundred of pay roll, and a policy covering such insurance is issued for 1 year. Pay rolls are submitted to the insurance Company's auditor, classification talked over with the contractor, and the rates for each applied. and the premium is based upon the entire pay roll.

PUBLIC LIABILITY INSURANCE

Coverage.—This form of insurance provides indemnity for the assured, against loss by reason of his legal liability to persons, other than employees, on account of construction operations performed by independent contractors or subcontractors for the owner or contractor. Employees are protected under Workmen's Compensation Insurance.

This insurance is ordinarily written at a $5000 limit for one person and $10,000 for more than one person. If protection is desired for an additional number of persons, the rates increase by a sliding percentage scale.

The minimum premium for a contractor's protective public liability insurance policy is $20 per year.

Rates.—In contractors' protective or contingent public liability insurance, the rates are based on a total cost of all work let or sublet in connection with each specific contract including costs of all labor, materials, and equipment furnished, used, or delivered for use in the execution of such work, whether furnished by the owner, contractor, or subcontractor, as well as allowances, bonuses or commissions, made, paid, or due, at the following rates:

Total cost up to and including $500,000, 10 cts. per hundred.

Total cost $500,001 up to and including $1,000,000, 6 cts. per hundred.

Total cost in excess of $1,000,000, 4 cts. per hundred.

HIGHWAY EQUIPMENT[1]

General Introduction.—Just by way of contrasting a 1926 plant, ıe writer wishes to enumerate the equipment used on the first ɔntract with which he was connected during the summer of 1900. This particular piece of highway improvement was a water-ound macadam, 16′ wide 6″ thick, built in two courses of 3″ each ı depth after consolidation. It included practically all of the reliminary work which has to be done on a present-day contract. he alignment was stacked out to tangents and regular curves as ı present-day methods, except that curves were not banked, ıe ditches were dug to line a grade, the drainage structure placed ; called for by the plans and, in short, except for the equipment sed and the thickness and depth of road metal, there was no ifference between present-day construction, except in the amount : mechanical equipment.

The list is given herewith:

steam roller at an approximate cost of	$2500.00
horse-drawn water tank for roller	150.00
ɔ doz. picks	120.00
ɔ doz. shovels	120.00
doz. sledges	15.00
knapping hammers	2.00
doz. iron pins for grade lines	2.50
600-gal. sprinkling wagons at $300 each	600.00

The above equipment plus the necessary pails, trowels, grading ring, and small incidentals were the only preliminary investments hich the contractor had to make inasmuch as the commissary ɔuses were built and paid for by the padrone who furnished the bor.

Labor was cheap and plentiful. As the author remembers it, the ages paid ran from 13½ cts. per hour for common labor to 30 :s. per hour to foremen. Carpenters were paid about 25 cts. per ɔur and inasmuch as teams could be hired at 35 cts. per hour cluding the driver, and slat dump wagons furnished by the owner, ıe contractor had no hauling equipment to buy.

It is not to be wondered at that, with so small an initial invest-ıent and with labor so cheap, the use of machinery to reduce costs as considered highly theoretical and scarcely to the liking of ɛperienced contractors.

The excavation of cuts and the placing of the material in fills ith a three-haul limit of 2000′ was done slowly and methodically y hand shovels, the dumped material spread with either shovels : rakes into 6″ layers. There was not even a slip scraper, wheeled :raper, or a road machine utilized on the entire 4-mile contract.

The first break away from these old-fashioned ideas, within the riter's experience which was largely confined to western New

[1] E. A. Bonney has supplied the general discussion of this item and the ɛtailed description of the common units of equipment. W. G. Harger ıs compiled the rental schedules and the approximate overhead equipment ıarges for unit price estimates.

York, came in 1910 in the substitution of bottom dump wagons fo slat wagons, and he well remembers the stock arguments whicl contractors and owners of teams would give the salesmen for dum wagons; that the team was too far from the load that they drew that the horses could not stand the extra strain, that the tear would be thrown by the sudden dropping of the load, etc.

It was not until the war conditions of 1916 to 1921, when labo was scarce, ineffective, and highly paid, that serious consideratio was given to the creation of portable mechanical units to take th place of hand labor. Steam shovels had been used for years o heavy work but were generally mounted on railroad wheels an built in sizes which precluded their passage over highway bridge of ordinary strength.

The development of the gas engine, both for motor trucks and i an industrial way for power units, kept pace with the scarcity labor; and within the last 10 years the development of mechanic equipment has been so rapid that present-day contracts are carrie on with a much smaller labor cost than ever before.

A list is herewith given of equipment which can be considere as entirely normal to any modern contractor building a road sever miles long under present-day methods.

1 10-ton three-wheeled motor roller with scarifier, approximate cost	$ 5,5
1 5-ton three-wheeled motor roller with planer and scarifier, approximate cost	2,5
1 motor-driven concrete mixer, caterpillar tread	7,5
1 motor-driven shovel, ¾-yd. bucket	12,0
8 2-yd. motor trucks with dump bodies at $3000 each	24,0
2 miles of 2″ water pipe with necessary unions, tees, and valves at 20 cts. per foot	2,0
1 motor-driven crane for unloading and storing materials	4,5
3000 lin. ft. of steel interlocking forms at 80 cts. per foot	2,4
1 motor grader	2,4
1 high-pressure water pump with gasoline engine	1,2
Necessary small tools, hammers, shovels, rakes etc.	..

If the contract in question is to be constructed from local stor the items in the above plant would be reduced by eliminating t loading crane, but increased by the addition of a crusher, elevat screen, and bins. In all probability an additional elevator a screen would be needed for the sand bank, with power to dri both units. It is obvious that with a reduction of 50% in t labor charge, an increase of several hundred per cent has occurr in the quantity of equipment needed.

In the modern method of handling highway work, however, the are additional viewpoints which must be considered and whi are made possible by the use of equipment. The present-d contractor wishes to average 2½ to 3 miles of road per mont whereas the old-time contractors, even the best of them, we satisfied with 6 or 7 miles per season. The traveling pub

mands speed, and without mechanical equipment this speed uld not be accomplished. It not only hastens the delivery and acing of materials, but in these very acts a modern plant functiong properly seems to speed up and maintain at a higher average e remaining labor element.

As an example, take the item of earth excavation. Present-day actice puts a steam or gas shovel through all cuts from 18″ up, e shovel feeding the motor trucks on which within the last 2 ars the use of pneumatic tires is rapidly increasing. The dumpg for the fill is taken at the point nearest the shovel so that the aded trucks are running over the new fill as the work progresses, ving a consolidation which cannot be equaled by any roller. ie dump bodies are designed to spread the load as the truck oves forward, thus eliminating almost entirely the necessity for bor on the fill. A motor grader, either on rubber tires or with a awler tread, works continuously on the new grade as it is built or cut down. The 10-ton gasoline-driven roller is put into eration within 2 or 3 min. and follows the rough grading operaon of the trucks and motor grader for the proper consolidation. hen the rough grading is complete, the heavier roller is laid aside d the fine grade largely finished with the use of a motor grader a 5-ton gasoline-driven roller equipped with a planer and scarifier.

When sufficient fine grading has been performed and the concrete vement started, partitions are installed in the dump trucks so at measured batches of stone and sand can be dumped directly to the hopper of the mixer. Portable turntables are provided that the trucks will not have to turn around a long distance om the mixer and back up to it; the cement can be loaded directly the mixer. The surface of the concrete pavement is oftentimes ished by mechanical and power-driven screeds. Water is ovided at the mixer by a high-pressure pump and pipe line, and e work progresses at an average speed which was not even thought 10 years ago.

If the pavement has been covered with a coating of earth for otection and curing, this is later removed without hand labor by e use of a power grader or a light road machine drawn by a iall tractor. In many instances the shoulders are built in the me manner and rolled with the small 5-ton roller.

The present-day methods practically exclude hand labor except the fine grade, the placing of forms, the distribution of concrete the mixer, and the covering of the finished concrete after the tial set together with the installation of culverts and the erection guard rails and signs.

This tendency toward the use of equipment in a much larger y than in the earlier days has proved its value to the public who e and pay for the highways and to that percentage of the concting fraternity who have proved its value to themselves. This me percentage of contractors who have brought the use of echanical means to its present-day development are of the type men who would have succeeded to approximately the same gree of success in any other line which they might have elected make a life work.

In other words the building of highways by contract has becon a specialty business, and the contrast between the fit and tl unfit is even more plainly marked than similar contrasts in mec cine, law, and general business. The requirements of preser day contracts should and do exclude the men working with litt or no capital, the inexperienced and the proven failure. T initial investment is such that a man without capital never h an even chance, except under very unusual circumstances. I cannot obtain a contract award and buy the necessary equipme from the earnings of the job as he could years ago. He should fitted with tools at the start which will allow him to perform t work at item prices as cheaply as his neighbor and competit It is perfectly obvious that the plant investment outlined abo properly to equip a road contract on which the contract pri may be $250,000, is all out of proportion to the cost of plant need for the erection of a $250,000 reinforced-concrete building or t laying of a $250,000 concrete-pipe sewer. We have heard tl complaint more than once, but it really has no bearing on t situation. The work is there to be done and it should be done the cheapest known way. We do not state that it is up to a co tractor to buy all of the equipment mentioned; we simply say th he needs it. If he can rent any or all of the equipment at a pr which will be cheaper for him at the end of his fiscal year or at t end of the contract than the outright purchase would be, and sa outright purchase price to include depreciation and interest investment, then let him rent what he needs and be rid of it at t end of his contract. This is a question where business training a experience enter. We have known contractors who by disrega ing the initial investment could show a good profit upon th work but went broke at the end of 2 or 3 years simply because depreciation of plant and continued interest charges on their pla investment. In other words their jobs were overplanted. closing these general remarks and before going further into itemi descriptions on costs and types of plant, we would like to rema that it takes a brilliant mind in addition to all other human co tracting qualities to enable a man or a corporation actively follo ing highway contracting to produce in the 6 or 8 months of go working weather what the same type of man in another line of wo would be content to accumulate in a business year of 12 months

Rollers.—For many years the steam roller was the standard se propelled machine common to all highway work, and at first purpose was simply compression of finished subgrade and the roll of macadam. About 10 years ago, a pressure scarifier, to attached to the rear of the machine for the purpose of tearing up roadbed, was perfected, and since that time the greater per c of rollers have been scarifier equipped. The steam roller is grad ally being retired in favor of the motor roller whose advanta are obvious, namely, elimination of hauling of coal and water a saving of time in stopping and starting the machine morning a night. A steam roller needs from 40 min. to an hour's work bef sufficient steam pressure can be obtaned to run and the fire l to be drawn or banked at night.

The motor roller carries sufficient gasoline to operate for a day and a half and water for cooling purposes for a week's operation; it can be started within a very few minutes, and when it stops, the expense ceases.

The so-called 10-ton three-wheeled motor rollers without scarifier cost approximately $4350 delivered, and with scarifier $5500. The machines are made in single-cylinder, double-cylinder, and four-cylinder motors. The heavy-duty single-cylinder and double-cylinder machines will probably last longer, as far as the motor is concerned, than the four-cylinder units; the motor speed is much less with the resulting longer life. There is however, more vibration in the slow-moving engine. One of the reasons for the rapid growth in the past few years in the use of four-cylinder machines is that the four-cylinder motor is better known to users of other motor equipment. More mechanics are familiar with the four-cylinder motor, as the construction of these motors is practically standard.

The use of a three-wheeled motor roller lighter than the 10-ton size is somewhat of an innovation, but has been adopted by a large number of states as standard specification for completion of subgrade. The machine is so much smaller than the 10-ton size that its advantages in using between the forms ahead of the concrete mixer are self-evident. Its use has been increased to a large extent by the addition of a planer blade on the front and a small scarifier on the rear, either and both of which are of great help in the final trimming up of subgrade just ahead of the laying of concrete.

A 5-ton three-wheeled motor roller with planer and scarifier costs approximately $2500 delivered.

Concrete Mixers.—The tendency of the past few years has been toward larger and more powerful mixers; a gasoline machine of crawler type, six-bag capacity, is the machine most popular with the present-day contractors. On the present models the stone, sand, and cement are generally dumped direct from the truck into a loading skip. As the skip is raised, water is automatically discharged into the mixing drum, the amount of water to be varied to use the material. The machines are steered by power operated by one man. The engine is generally a four-cylinder gasoline motor, radiator cooled; all gears are enclosed; it is equipped with roller bearings and lubricated in the automatic way in general use on automobile trucks. The price of a machine of this size is $7700 delivered.

Steam or Motor Shovels.—A few years ago before the rapid development of the gasoline motor, the use of a power shovel by highway contractors was not considered unless the excavation quantities ran above 8000 to 10,000 cubic yards per mile of highway. At that time it was thought that a face of 4 or 5′ in any given cut was needed for the economical use of a power shovel, and with the old system of hauling material away from the shovel by means of horses and wagons, the contractors were probably correct in their contention. The development of the high-speed smaller truck with pneumatic tires with a capacity of from 2 to 2½ yd. has changed the situation to such an extent that power shovels are

now used on any type of excavation where the cut will average 8″. There never has been any difficulty with getting a power shovel to dig, the main difficulty being getting the material away from the machine. The use of the fast-moving light trucks has solved the problem, and the further development of the shovels themselves by equipping with gasoline motors has brought about a tremendous impetus in the use of this type machine.

The shovels are generally equipped with crawler treads, which eliminate the necessity for planking ahead of the wheels and enable them to work on soft ground. The size bucket varies from ½ to ⅞ yd.

The price of a gasoline shovel of this capacity equipped with crawler treads is approximately $12,000 delivered, steam shovels running about two-thirds as much.

Motor Trucks.—Except where their use is confined to city pavements, the 5-ton truck and larger sizes are being superseded to a large extent by the smaller, quicker, and less costly units of 2 to 2½ tons. The latter trucks have the same equipment as to automatic dump bodies as the heavier machines, but where they are used for concrete operations, they handle only two batches instead of five or more. They are generally equipped with pneumatic tires and are capable of speeds of 25 to 30 miles per hour. They are more easily handled on turntables, do not cut up the subgrade as much as the large trucks, and in general are easier to operate and to keep in running condition. The pneumatic tires save repair bills on both the motor and hoisting apparatus. The bodies are made in a large number of types but generally are rear dump. A fair average cost for trucks of this kind is $3000 delivered.

Crane.—The use of a portable crane is one of the recent developments brought about by the necessity for transfer of materials for short distances, such as unloading from storage cars to storage piles, and reloading from storage piles to trucks or measuring bins. No contractor at the present time wishes to depend upon daily shipments of stone and sand. He needs a storage pile of each as a factor of safety against the possibility of non-delivery by the railroad, and while this means an extra handling of the material, the cost is saved by the guarantee of no interruptions.

One of the most elastic units is shown herewith in the crane mounted on a chassis of a 5-ton truck. The crane itself is driven by a separate engine, the truck motor furnishing only the power for traveling. The machine can be utilized in many other ways, namely, the pulling of stumps, the handling of heavy timbers, unloading and laying cast-iron pipe, digging trenches for culverts, etc. The price of the crane complete with all attachments ready for mounting on the chassis of the truck is approximately $4650 delivered.

Graders.—The item of earth excavation in highway contracts is one that for many years has been a source of trouble and loss to the contractor rather than showing a possibility of profit. Of course, where the excavation ran sufficiently high so that most of the material could be handled with power shovels and taken away by motor trucks, there was less complaint, but on a lighter excava-

tion running 3000 or 4000 yds. per mile, the work if done by hand was almost certain to be a losing item.

The development of the motor grader has done much to change these conditions. The machine weighs from 6000 to 12,000 lb. according to size and power; for construction on rough ground it is equipped with crawler treads; and it is used continuously in leveling the newly dumped material or in combination with a scarifier handles light excavating work. Except in the case of the elevating grader, it is not intended to pick up the material but rather to push it ahead or to one side, and there are cases where because the excavation in general average thickness was too small for economical use of a power shovel, a motor grader was used to windrow the excavated material so that the power shovel could pick it up more easily.

Motor graders with rubber-tired equipment run from $1800 to $3300 according to power plant and weight. In the crawler type they run from $2100 up to $4300. The choice of machine depends entirely on the amount and character of work to be done.

For maintenance work the rubber-tired equipment works to advantage. It can travel faster than the crawler tread, but of course its use is pretty well restricted to shoulder work on hard-surface roads before scarifying and reshaping on gravel roads. No wheeled machine will work satisfactory in sand and it will bury itself by its own tractive efforts in mud.

Road Graders.—A type of machine seldom seen in the eastern part of this country, which, however, has widespread use in the middle and far west, is the elevating grader. The chief reason for its scarcity in the eastern territory is the lack of sufficient width of the highways for economical handling of the machine. It consists of a plow, either of the moldboard or disc type, and the act of cutting a furrow throws the material on a moving belt which casts it to one side, either directly into an embankment or into trucks, wagons, or cars. The machine travels ordinarily at the rate of 1½ miles per hour, and figuring from the length, width, and depth of the furrow, theoretically the machine will deliver approximately 1500 cu. yd. of earth in a 10-hr. day.

Of course not all theories measure up in actual work performed, but bonafide estimates and reports from contractors using the machine show an average of 1000 cu. yd. per day in material which can be easily plowed. The elevating grader will do this work from one-fourth to one-third cheaper than the cost of other methods.

Blade Graders.—These machines are intended to supplement the use of elevating graders, steam shovels, and all other means of handling earth, by cutting off the high spots in the grade and pushing the material either forward or to one side into low spots. That is a condensed statement of the work which graders perform. It is true that they are utilized particularly with a back sloper attachment for digging ditches, but the main work of the grader will always be the reshaping of subgrade, either in cut or fill.

The graders run through all weights from 1000 to 11,000 lb., pulled by one team or a 10-ton tractor as limits. They run in

price from $150 to $2500 according to equipment. More modern machines have leaning wheels, Timken roller bearings, and sometimes attached scarifiers. When used for maintenance work, they are often equipped with rubber tires.

Water Pumps.—There is no single unit in the contractors' plant on the construction of concrete roads which is more worthy of quality in choice and performance than the pump. This point has been emphasized to such an extent as to have two pumps on the job, one to cut in as an extra in case anything should happen to the one in use. If the water stops, the concrete stops, and the whole job is disorganized. (a) Duplex pump and engine mounted on one truck with a capacity of 40 gal. per minute, 175 pounds pressure, maximum head 407 feet, costs approximately $620.00; a single unit with a capacity of 80 gallons per minute, working under a pressure of 500 pounds maximum head of 1125 feet, would cost $1630.00. Both prices f.o.b. destination.

The above-listed equipment covers what might be called the average list of units which the highway contractor needs continuously. There are a large number of special tools which he needs only occasionally, and it is not necessary in a book of this kind to go into specialized equipment such as air compressors, pile drivers, pavement-cutting tools, etc. When a unit of this kind is needed, the contractor generally figures it for one job only and charges the entire cost and depreciation for the one job which it is to perform. This procedure puts this type of equipment in a different classification from the list given above, which can be utilized on practically every job at sometime or other.

WATER SUPPLY DATA FOR CONCRETE PAVING*

The State Highway Department of Pennsylvania has compiled the following information for use in determining the sizes of pipe line to be used for the water supply on concrete paving projects. The information is based upon 50% of the water being required for curing and 50% being required for the mixer and subgrade curing. The department states that if calcium chloride is used for curing the amount of water required for the lengths paved per hour can be reduced one-half.

The tables given under the sizes of pipe lines are figured without modifications for head, and the table at the bottom of the tabulation gives the information for the correction for the head.

The tables are based on a requirement of 8000 gal. of water for 100 ft. of paving apportioned as follows: ½ for curing, ¼ for subgrade, ¼ for mixer. The pavement is assumed to be 18 ft. wide. The head given is based on friction loss only. To this must be added the height of the outlet of the pipe above the source of supply.

* Roads and streets, May, 1927.

Water Supply Data

Loss of head due to friction in steel pipes for water used in paving

Length paved per hr. ft.	Gal. water required per hr.	V feet per sec.	Length of pipe					
			½ mi.	1 mi.	1½ mi.	2 mi.	2½ mi.	3 mi.
2-inch pipe								
...	2000	3.188	79	158	237	316	395	474
...	2400	3.825	111	222	333	444	556	667
...	2800	4.463	148	296	445	593	741	889
...	3200	5.100	190	381	571	761	952	1142
...	3600	5.738	237	474	711	948	1186	1423
50	4000	6.37	288	577	866	1155	1444	1732
60	4800	7.65	406	812	1218	1624	2030	2436
70	5600	8.92	542	1083	1625	2167	2708	3250
80	6400	10.20	695	1391	2086	2781	3477	4172
90	7200	11.47	867	1733	2600	3466	4333	5200
100	8000	12.75	1055	2111	3166	4221	5277	6332
2½-inch pipe								
...	2000	2.233	33	65	98	130	163	195
...	2400	2.679	46	91	137	183	229	274
...	2800	3.126	61	122	183	244	305	366
...	3200	3.572	78	157	235	313	392	470
...	3600	4.019	98	195	293	390	488	586
50	4000	4.47	119	238	357	476	595	714
60	4800	5.36	167	335	502	669	836	1004
70	5600	6.25	223	446	669	893	1116	1339
80	6400	7.15	286	573	859	1146	1432	1719
90	7200	8.04	357	714	1071	1428	1785	2142
100	8000	8.93	435	870	1304	1739	2174	2609
3-inch pipe								
...	2000	1.448	11	22	33	44	55	66
...	2400	1.737	16	31	47	62	78	93
...	2800	2.027	21	41	62	83	104	124
...	3200	2.316	27	53	80	106	133	159
...	3600	2.606	33	66	99	132	166	199
50	4000	2.89	40	80	121	161	201	241
60	4800	3.47	57	113	170	226	283	339
70	5600	4.05	75	151	226	302	377	453
80	6400	4.63	97	194	291	388	485	581
90	7200	5.21	121	242	362	483	604	725
100	8000	5.79	147	294	441	588	736	882

Head, ft.	Pressure per sq. in.	Head, ft.	Pressure per sq. in.	Pressure per sq. in.	Head, ft.	Pressure per sq. in.	Head, ft.
10	4	200	87	4	9.2	50	115
20	9	300	130	5	11.5	60	138
30	13	400	174	6	13.8	70	161
40	17	500	217	7	16.1	80	184
50	22	600	260	8	18.4	90	207
60	26	700	304	9	20.7	100	230
70	30	800	347	10	23	200	461
80	35	900	391	20	46	300	691
90	39	1000	434	30	69	400	922
100	43	2000	868	40	92	500	1152

The formula used is the Hazen-Williams Formula:

$$H = K \frac{lv^{1.87}}{d^{1.25}}$$ in which

H = loss of head due to friction
K = .00038
l = length of pipe in feet
v = velocity of water in feet per second
d = diameter of pipe in feet
A 2 -in. pipe = 2.067 internal diameter.
A 2½-in. pipe = 2.469 internal diameter.
A 3 -in. pipe = 3.068 internal diameter.

How the Tables Are Used.—Example (1):

Estimated progress of paving 70 ft. per hour. Water required—5600 gal. per hour.

Maximum water pressure in pump—150 lbs. per square inch.

Pipe 2-in. diameter, pump 12 ft. above level of supply. Outlet 40 ft. above pump.

How far from the pump can the work be supplied?

150 lb. pressure = 345 ft. head as per conversion table. 345 − 12 − 40 = 293 ft. net head.

The head required for 1 mile of pipe is 1083 ft. Distance water can be supplied $= \frac{293}{1083} =$ ¼ mile.

Example (2):

Estimated progress of paving—70 ft. per hour.

Maximum water pressure in pump—500 lb. per sq. in.

Maximum distance water must be forced = 2½ miles.

What size pipe is required?

500 lb. = total water pressure available, which corresponds to 115[illegible] ft. head.

2-in. pipe under these conditions requires 2706 ft. head or 1175 lb pressure and is too small.

2½-in. pipe is necessary and requires 1116 ft. head; which corresponds to 484 lb. pressure.

A 3-inch pipe requires 337 ft. head which corresponds to 163 lb pump pressure.

Example (3):

Estimated progress per hour = 90 ft.

Distance water must be forced = 2½ miles. What horsepowe[r] and pressure are required?

2-in. pipe requires 4333 ft. head by table or 1880 lb. pressure.

Water required = 7200 gal. per hr. = 2 gal. per sec. = 16.7 lb. pe[r] sec.

16.7 by 4333 = 72,360 ft. lb. per sec. ÷ 550 = 132 horsepower.

2½-in. pipe would require 1785 ft. head by table or 775 lb. pressure

16.7 by 1785 ÷ 550 = 54 horsepower.

3-in. pipe would require 604 ft. head by table or 250 lb. pressure.

16.7 by 604 ÷ 550 = 18 horsepower.

RENTAL SCHEDULE FOR ESTIMATING CONSTRUCTION EQUIPMENT EXPENSE[1]

A schedule, evolved from the records and experiences of contractors, manufacturers, and rebuilders of equipment, and designed to furnish contractors with a practical means for estimating equipment expense and determining adequate rental charges has been approved by the Executive Board of the Associated General Contractors. The schedule, which was prepared by the Research Division under the direction of the Committee of Methods of the Association, is printed in the November *Bulletin* of the Associated General Contractors. The schedule and discussion of its application follow.

To use the schedule with safety, it is essential to understand how the amounts were obtained, how they are to be applied, and how they are limited for determining rental charges. Knowing these things, no great difficulty should be found in establishing the charges within the bounds of practical accuracy.

For the reason that arithmetical averages, as obtained from available records, gave few rational values for depreciation and repairs, such averages were given less weight in establishing the tabular amounts than the practical experience of contractors. In fact, the strongest evidence that these amounts are reasonably safe and accurate lies in the endorsement given them by experienced general contractors.

A tentative draft of the schedule was submitted to members in the *Weekly Bulletin* of July 31. They were asked to criticise the amounts and offer suggestions. In accordance with the criticism received, which evinced considerable study upon the subject, some of the tabular amounts were changed. As it now stands, the schedule represents the consensus of opinion of many contractors, and with the proper understanding of what the percentage amounts mean, it should offer a safe means of estimating rental charges.

What the Values Mean.—The endless variation of job conditions, such as topography, ground formation, and climate, indicate how great may be the error of any fixed equipment charge when applied to the exceptional job. But having figures which represent the mean of many projects, a starting point exists for ascertaining reasonable charges for the exceptional circumstances. Figures given in the standard schedule may be said to show equipment expense when machines are not required to operate continuously under either the worst or the best of operation strain. When no especially favorable or unfavorable circumstances attend a project, the tabular values probably give the expense within a permissible error.

To eliminate error as far as possible by permitting consideration and comparison of the individual items that make up equipment expense, the gross amounts are reduced to their component parts. Thus any item of the expense which is known to be unusually high in specific cases may be adjusted in the schedule to obtain a more appropriate rental rate.

[1] General Contractors' Association.

Components of Expense.—Seven items of equipment expense constitute the total rental charge and require consideration in estimating a lump-sum contract or in determining fixed-rate rentals. An average value for each of these items which represent the expense of a general contractor's outfit as a whole has been approved by the Executive Board. The items referred to and their annual proportions of the initial cost of the equipment are as follows:

Schedule of Typical Rental Charge.—Items of expense are expressed as per cents of original capital investment for equipment having a useful life of 6 years and a salvage value of 25% of the original cost.

	%
1. Average depreciation	12½
2. Equivalent annual interest at 6½%	4
3. Shop repairs	6
4. Field repairs	4
5. Storage and incidentals	3½
6. Insurance	1
7. Taxes	1
Total annual expense	32
Equivalent expense on basis of 8 months working time per year	48
Rental rate per month	4

How to Obtain Proper Percentage.—These percentages and those given in the detailed schedule were determined according to the following principles:

The economical life of a machine is considered to end when its value has depreciated to 25% of the original cost. The average annual depreciation then amounts to 75% of the initial cost divided by the number of years it may be expected to give service. The initial cost of a machine is represented by the cost of that machine delivered at the contractor's yard.

Interest should naturally be charged at the prevailing rate. This may be computed in three ways:

1. By charging the prevailing rate each year on the depreciated value of the machine.

2. By charging the prevailing rate each year on the average value of the machine during economical life. For example, when the salvage rate value is 25% the average value equals (100% + 25%) divided by 2 = 62½%.

3. By finding the proportion which the average value is of the initial cost and charging this proportion of the prevailing rate each year. This proportion is called the equivalent annual interest and shows what interest rate on original cost will yield the same interest as the prevailing rate when applied to the depreciating value of the machine. This is the method used in the above schedule. The average value is 62½% of the original; therefore, the equivalent annual rate is 62½% of the prevailing rate, or 62½% of 6½% = 4%.

Shop and field repairs are separated by reason of a previous recommendation of the Committee on Methods that field repairs

BLE 223*A*.—RENTAL SCHEDULE FOR CONSTRUCTION EQUIPMENT

Items of equipment	Economical length of life, years	Annual depreciation, %	Annual shop repairs, %	Annual field repairs, %	Storage and incidentals, %	Insurance, %	Taxes, %	Total annual charge % initial investment
sphalt mixing plant	..	....	..	..	....	..	..	40
uto crane	5	15	6	5	3½	1	1	31½
uto truck	3	25	20	20	3½	1	1	70½
uto trailer	5	15	6	5	3½	1	1	31½
ackfiller, power	4	18¾	6	7	3½	1	1	37¼
allast spreader	8	9½	6	4	3½	1	1	25
oiler, upright	8	9½	20	5	3½	1	1	40
oiler, locomotive	8	9½	15	5	3½	1	1	35
ucket, clam shell	4	18¾	15	6	3½	1	1	45¼
ucket, orange peel	4	18¾	25	6	3½	1	1	55¼
ucket, dragline	4	18¾	12	3	3½	1	1	39¼
ars, steel dump	6	12½	8	4	3½	1	1	30
ars, wood dump	5	15	7	3	3½	1	1	30½
ars, flat	8	9½	4	3	3½	1	1	22
ars, hopper	5	15	8	3	3½	1	1	31½
ompressor, steam	7	10¾	6	3	3½	1	1	25¼
ompressor, gasoline	4	18¾	6	7	3½	1	1	37¼
ompressor, electric	6	12½	3	3	3½	1	1	24
oncrete chutes	2	37½	15	15	3½	1	1	73
onveyor, belt	2	37½	7	6	3½	1	1	56
onveyor, bucket	2	37½	10	6	3½	1	1	59
rusher, rock	6	12½	5	3	3½	1	1	26
errick, wood	5	15	4	4	3½	1	1	28½
errick, steel	10	7½	4	3	3½	1	1	20
ragline, steam	6	12½	9	8	3½	1	1	35
ragline, gasoline	4	18¾	10	10	3½	1	1	44¼
ragline, electric	8	9½	7	7	3½	1	1	29
rill, tunnel carriage	5	15	8	8	3½	1	1	36½
rill, traction well	6	12½	7	10	3½	1	1	35
rill, tripod	4	18¾	7	10	3½	1	1	41¼
rill, jack hammer	4	18¾	7	6	3½	1	1	37¼
ngine, gas	6	12½	8	8	3½	1	1	34
ngine, steam	10	7½	5	5	3½	1	1	23
xcavator, cableway	6	12½	4	12	3½	1	1	34
xcavator, Keystone	5	15	8	4	3½	1	1	32½
xcavator, trench	5	15	8	6	3½	1	1	34½
orms, steel concrete	2	37½	20	20	3½	1	1	83
raders, common road	4	18¾	12	6	3½	1	1	42¼
raders, elevating	4	18¾	15	7	3½	1	1	46½
oist, steam	10	7½	6	4	3½	1	1	23
oist, gasoline	6	12½	7	8	3½	1	1	33
oist, electric	8	9½	5	3	3½	1	1	23
ocomotive:								
Industrial steam	9	8½	6	4	3½	1	1	24
Industrial gas	4	18¾	13	10	3½	1	1	47¼
Industrial battery	4	18¾	15	4	3½	1	1	43¼
Standard gage	10	7½	6	4	3½	1	1	23
Crane, steam	8	9½	7	8	3½	1	1	30
Crane, electric	8	9½	6	4	3½	1	1	25

TABLE 223*A*.—*Continued*

Items of equipment	Economical length of life, years	Annual depreciation, %	Annual shop repairs, %	Annual field repairs, %	Storage and incidentals, %	Insurance, %	Taxes, %	Total annual charge % initial investment
Mixer, steam	5	15	12	4	3½	1	1	36½
Mixer, gasoline	4	18¾	13	8	3½	1	1	45¼
Mixer, electric	6	12½	12	4	3½	1	1	34
Mixer, paving steam	5	15	13	4	3½	1	1	37½
Mixer, paving gas	3	25	16	9	3½	1	1	55½
Motors	6	12½	6	4	3½	1	1	28
Pile driver, steam	8	9½	7	5	3½	1	1	27
Pile driver, track	10	7½	5	3	3½	1	1	21
Pile hammer, steam	7	10¾	7	3	3½	1	1	26¼
Pipe, galvanized	3	25	5	6	3½	1	1	41½
Plows	3	25	15	10	3½	1	1	55½
Pneumatic concrete machine	4	18¾	20	8	3½	1	1	52¼
Pump, centrifugal	8	9½	6	4	3½	1	1	25
Pump, piston	6	12½	7	5	3½	1	1	30
Pump, pulsometer	8	9½	2	4	3½	1	1	21
Pump, Emerson	8	9½	2	4	3½	1	1	21
Rails	8	9½	5	3	3½	1	1	23
Riveter, air	5	15	8	4	3½	1	1	32½
Rock channeler	6	12½	7	8	3½	1	1	33
Roller, steam road	10	7½	5	3	3½	1	1	21
Saw rigs	4	18¾	10	15	3½	1	1	49¼
Scraper, wheel	3	25	8	4	3½	1	1	42½
Scraper, slip	1	75	25	10	3½	1	1	115½
Scraper, Fresno	2	37½	25	15	3½	1	1	83
Shovel, steam	6	12½	7	6	3½	1	1	31
Shovel, gasoline	4	18¾	9	7	3½	1	1	40¼
Shovel, electric	7	10¾	6	5	3½	1	1	27¼
Switches, fabricated	3	25	3	3	3½	1	1	36½
Tower, steel hoist	7	10¾	3	4	3½	1	1	23¼
Tractor, wheel gas	6	12½	9	5	3½	1	1	32
Tractor, caterpillar	5	15	15	10	3½	1	1	45½
Wagons, dump	4	18¾	17	3	3½	1	1	44¼
Wagons, hauling	4	18¾	12	3	3½	1	1	39¼
Wagon loaders, power	5	15	10	6	3½	1	1	36½

be considered a part of the cost under cost plus contracts and sh repairs be borne by the contractor and covered by the fixed-ra rental charge. This recommendation was made on the grou that an owner should not be made to pay the total cost, for examp of re-fluing a boiler which may have been burned out principa on another owner's work.

The other items of cost require no special explanation.

Three Types of Charges.—Owners of equipment find occasi to establish rental rates as follows:

1. For a lump sum or unit price estimate.
2. To owners on cost plus work.
3. To others than client owners.

In these instances charges should be made as follows:

1. The rental charge or equipment expense for lump sum work cludes all the items mentioned above.

2. The fixed rate to owners on cost plus work will include all ut field repairs, if this item is paid as a cost of the work. To ie amount thus determined may be added a service charge epending upon the policy of the contractor, *i.e.*, whether the rvice of equipment is included in the profit fee or carried in the ntal charge.

3. The charge to persons other than client owners includes all the items of expense and an additional amount for profit or ayment for the machine's earning power.

A further consideration in each of these cases is the rate for ouble-shift work, where the percentages for depreciation and pairs should be doubled, or nearly so.

Individual Judgment Essential.—The committee desires to nphasize the fact that the values presented in the table should not considered absolute in determining a rental charge. A real anger presents itself in using any tabular percentage without vestigating the conditions under which the equipment is to work. o illustrate: If the values here given for a standard-gage shovel itfit were applied to such an outfit engaged constantly in excavatg hard rock, the probability is that the charges allowed would not over more than half the expense. The frequent dobey shots and ie dropping of heavy boulders into cars entails a higher rate of epreciation and repairs than is given in the schedule. On the her hand, if this shovel outfit were steadily engaged in digging ndy loam, the values given in the table would probably cause ie equipment charge to contain a fair per cent of profit.

It is with the understanding that individual judgment and perience should adjust the tabular values to meet unusual contions that this schedule is offered to contractors.

Individual Equipment Rental Schedule.—The component penses incurred by the ownership and maintenance of construcon plant are expressed in this table as percentages of the initial ost for individual items of equipment. They indicate the probae annual expense without profit under ordinary job conditions id should be included in any lump-sum estimate or in determining me-rate rental charges. The salvage value in all cases is condered to be 25 per cent of the initial cost.

Total percentage amounts in the extreme right-hand column ould be applied to the total cost of a machine, including charges r transportation from the factory. This gives the total annual arge which for a lump-sum contract covering a full season, is e total equipment expense. For determining a monthly, weekly, daily rental rate the annual amount is divided by the number of ch periods in the year during which construction work may carried on.

Table 223*B* giving rental rates for grading equipment has been mpiled by F. J. Herlihy, of Minneapolis, Minn. The table, hich is reprinted below, shows the original capital cost of his equipent, depreciation charges, average earning days per year, daily arge for interest, depreciation, insurance and storage, and total ily rental charge:

TABLE 223B.—RENTAL RATES FOR GRADING CONTRACTORS EQUIPMENT

Class of equipment	Original capital cost (1920)	Equivalent annual interest rate on original cost, per cent	Annual rate of depreciation on original cost, per cent	Annual insurance and storage rate on original cost, per cent	Total annual rate of accrued charges on original cost, per cent	Total annual charge	Average earning days per year	Daily charge for int., dep., ins. and storage	General shop repairs daily	Daily rental	Estimated cost field repairs daily	Total rental charge daily, including field repairs
Steam shovel	$12,000	3¾	12½	3¾	20	$2,400.00	200	$12.00	$4.00	$16.00	$4.00	$20.00
Steam shovel	20,000	3¾	12½	3¾	20	4,000.00	200	20.00	6.00	26.00	6.00	32.00
Steam shovel	30,000	3¾	12½	3¾	20	6,000.00	200	30.00	9.00	39.00	9.00	48.00
Steam shovel	90,000	3¾	12½	3¾	20	18,000.00	200	90.00	25.00	115.00	25.00	140.00
Dragline excavator	20,000	3¾	12½	3¾	20	4,000.00	200	20.00	10.00	30.00	10.00	40.00
Dragline excavator	30,000	3¾	12½	3¾	20	6,000.00	200	30.00	15.00	45.00	15.00	60.00
Standard-gage locomotive	12,000	3¾	12½	3¾	20	2,400.00	200	12.00	5.00	17.00	5.00	22.00
Standard-gage locomotive	16,000	3¾	7½	3¾	15	2,400.00	200	12.00	6.00	18.00	6.00	24.00
Standard-gage locomotive	24,000	3¾	7½	3¾	15	3,600.00	200	18.00	8.00	26.00	8.00	34.00
Dinkey locomotive	4,000	3¾	12½	3¾	20	800.00	200	4.00	1.50	5.50	1.50	7.00
Dinkey locomotive	6,000	3¾	12½	3¾	20	1,200.00	200	6.00	2.50	8.50	2.50	11.00
Locomotive crane	20,000	3¾	12½	3¾	20	4,000.00	200	20.00	6.00	26.00	6.00	32.00
Jordan spreader	9,000	3¾	12½	3¾	20	1,800.00	200	9.00	3.00	12.00	1.00	13.00
Rail, per ton	48	3¾	7½	3¾	15	7.20	200	0.04	0.01	0.05	0.00	0.05
Track-throwing machine	6,000	3¾	12½	3¾	20	1,200.00	200	6.00	2.00	8.00	1.00	9.00
20-yd. air dump cars	3,750	3¾	12½	3¾	20	750.00	200	3.75	0.25	4.00	0.25	4.25
16-yd. air dump cars	2,800	3¾	12½	3¾	20	560.00	200	2.80	0.20	3.00	0.25	3.25
12-yd. air dump cars	2,000	3¾	12½	3¾	20	400.00	200	2.00	0.15	2.15	0.15	2.30
4-yd. dump cars	430	3¾	12½	3¾	20	86.00	200	0.43	0.07	0.50	0.10	0.60
1½-yd. dump cars	110	3¾	12½	3¾	20	22.00	200	0.11	0.09	0.20	0.10	0.30
1-yd. dump cars	90	3¾	12½	3¾	20	18.00	200	0.09	0.06	0.15	0.10	0.25
Flat cars	1,000	3¾	7½	3¾	15	150.00	200	0.75	0.15	0.90	0.10	1.00
Gasoline locomotive	3,200	3¾	12½	3¾	20	640.00	200	3.20	1.05	4.25	1.25	5.50
1-yd. Koppel cars, V-shape	110	3¾	12½	3¾	20	22.00	200	0.11	0.04	0.15	0.05	0.20
Motor truck, 5 ton	6,000	3¾	22½	3¾	30	1,800.00	200	9.00	7.50	16.50	5.00	21.50
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	50	1,000.00	200	5.00	2.50	7.50	2.50	10.00

Locomotive boiler........	1,500	3¾	7½	3¾	15	225.00	100	2.25	1.00	3.25	0.00	3.25
Steam pump.............	500	3¾	7½	3¾	15	75.00	100	0.75	0.50	1.25	0.00	1.25
Centrifugal pump, d.c.....	1,500	3¾	7½	3¾	15	225.00	100	2.25	1.25	3.50	0.50	4.00
Belted pump.............	300	3¾	7½	3¾	15	45.00	100	0.45	0.30	0.75	0.00	0.75
Deep-well pump..........	600	3¾	7½	3¾	15	90.00	100	0.90	0.60	1.50	0.00	1.50
Gasoline engine...........	1,200	3¾	7½	3¾	15	180.00	100	1.80	0.60	2.40	0.10	2.50
Steam engine.............	1,800	3¾	7½	3¾	15	270.00	100	2.70	0.90	3.60	0.15	3.75
Hoisting engine...........	4,250	3¾	7½	3¾	15	637.50	100	6.38	2.12	8.50	0.50	9.00
Horse pile driver..........	800	3¾	12½	3¾	20	160.00	100	1.60	0.40	2.00	0.00	2.00
Steam pile driver.........	2,000	3¾	12½	3¾	20	400.00	100	4.00	0.75	4.75	0.75	5.50
Track pile driver..........	10,000	3¾	7½	3¾	15	1,500.00	100	15.00	3.00	18.00	2.00	20.00
Steam pile hammer.......	2,500	3¾	7½	3¾	15	375.00	100	3.75	0.75	4.50	0.50	5.00
Air compressor...........	3,000	3¾	7½	3¾	15	450.00	100	4.50	1.50	6.00	0.50	6.50
Electric motor............	500	3¾	12½	3¾	20	100.00	100	1.00	0.35	1.35	0.15	1.50
Deep-well drill............	2,000	3¾	12½	3¾	20	400.00	100	4.00	0.50	4.50	0.50	5.00
Steam tripod drill.........	400	3¾	12½	3¾	20	80.00	100	0.80	0.20	1.00	0.25	1.25
Jack-hammer drill........	140	3¾	12½	3¾	20	28.00	100	0.28	0.22	0.50	0.25	0.75
Air steel sharpener........	2,000	3¾	12½	3¾	20	400.00	100	4.00	0.25	4.25	0.25	4.50
Stiff-leg derrick...........	2,000	3¾	12½	3¾	20	400.00	100	4.00	0.50	4.50	0.75	5.25
Forrest log loader.........	400	3¾	12½	3¾	20	80.00	100	0.80	0.20	1.00	0.25	1.25
Lee wagon loader.........	225	3¾	12½	3¾	20	45.00	100	0.45	0.15	0.60	0.15	0.75
Clam-shell bucket.........	1,500	3¾	12½	3¾	20	300.00	100	3.00	0.25	3.25	0.25	3.50
Rock-channeler machine...	3,000	3¾	12½	3¾	20	600.00	100	6.00	2.00	8.00	1.00	9.00
Grading machine.........	1,350	3	23¼	3¾	30	405.00	150	2.70	1.30	4.00	1.00	5.00
Pony road grader.........	200	3	23¼	3¾	30	60.00	150	0.40	0.20	0.60	0.15	0.75
Grading plow.............	30	3	23¼	3¾	30	9.00	150	0.06	0.04	0.10	0.00	0.10
Dump wagon.............	180	3	23¼	3¾	30	54.00	150	0.36	0.34	0.70	0.15	0.85
Hauling wagons..........	120	3	23¼	3¾	30	36.00	150	0.24	0.21	0.45	0.15	0.60
Wheel scrapers...........	50	3	33¼	3¾	40	20.00	150	0.13	0.12	0.25	0.00	0.25
Slip scrapers.............	8	3	43¼	3¾	50	4.00	150	0.03	0.02	0.05	0.00	0.05
Fresno..................	22	3	43¼	3¾	50	11.00	150	0.07	0.08	0.15	0.00	0.15
Switches, complete........	150	3¾	7½	3¾	15	22.50	200	0.11	0.02	0.13	0.00	0.13
2-in. galvanized pipe, per 100'..................	22	3¾	7½	3¾	15	3.30	200	0.02	0.01	0.03	0.00	0.03
2½-in. galvanized pipe, per 100'..................	34	3¾	7½	3¾	15	5.10	200	0.03	0.01	0.04	0.00	0.04
3-in. galvanized pipe, per 100'..................	45	3¾	7½	3¾	15	6.75	200	0.04	0.01	0.05	0.00	0.05

RENTAL CHARGES FOR CONSTRUCTION EQUIPMENT

In connection with the preparation of a standard list of renta charges for construction equipment, a committee of the Associatec General Contractors of America has been collecting informatior as to the practice of various contractors in this matter. In the January 10, 1920 *News Letter* of the association the following schedul of rental charges, submitted by an eastern contractor, is given

TABLE 223*C*

Equipment	Weekly Rental
Boiler, only, 30 hp. and smaller	$12.00
Boiler only, 30 to 60 hp	16.00
Bucket, clam shell, ¾ yd	15.00
Cars, skip, 1½ yd	2.00
Cars, steel, 1 yd. and smaller	1.50
Crusher only, Acme No. 9½	22.00
Cutter, bar portable, with motor	9.50
Derrick, 30 to 59′, wooden, homemade	3.00
Drill, small air	3.00
Drill, steam	4.50
Elevator, platform or bucket, 1 yd	2.00
Engine, skeleton, 2-drum, 20 hp	8.00
Engine, gasoline, to 8 hp	3.00
Engine, gasoline, 10 hp	5.00
Leveling instrument, engineers'	1.50
Mixers, with gasoline engine, 11 to 15′ cap	15.00
Motors, 2 hp	1.50
Motors, 5 hp	2.50
Motors, 10 hp	3.50
Motors, 25 hp	5.00
Motors, 50 hp	9.00
Pumps, centrifugal, 10 in., belt driven, with engine	7.00
Pumps, pulsometer, to 4 in	6.00
Pumps, 3-in., with gasoline engine	3.500
Pumps, diaphragm, with gasoline engine	3.5
Saw benches, plain	3.00
Saw benches, plain, with motor or gas engine attached	5.50
Saw swing cutoff, no power	1.00
Steam shovels, revolving, traction, per day	24.00
Transit	2.00

[1] Per day.

In submitting the list, the contractor wrote as follows concernin his firm's policy on equipment rental:

The plant rental sheet was revised the first of this year and wil be revised again for another year, probably upwards. *Our renta basis for our own work is entirely that of replacement cost.* Al plant costing $150 or more whose life extends over a period o years or over several jobs is shown on our detailed list, which i compiled from our experience of the probable life of each tool There are three classes:

Class *A*—Tools which will last through 50 weeks of continuou work.

Class *B*—Tools which will last through 75 weeks of continuou work.

[1] Engineering Contracting, Jan. 21, 1920.

Class *C*—Tools which will last through 100 weeks of continuous work.

Our rental is sufficient to produce enough revenue to make extraordinary repairs and to replace the plant at the end of this length of time.

You will find that these rentals are uniformly low because they are at cost to ourselves and apply on jobs where we are operating the plant. These plant rentals go into a cost plus or fixed fee contract as a part of the job cost on which profit is figured.

If we rented the plant to outsiders we would charge about half as much again for it.

Our method of handling small tools such as shovels, picks, hammers, etc., is to charge their entire cost to the job. If they are worn out they become part of the job cost. At the completion of the work an inventory is taken and each tool is appraised in cooperation with a representative of the owner. We have five grades: (1) New, 100% of first cost; (2) good, 75%; (3) fair, 50%; (4) poor, 25%; (5) worthless, 0%. We take them back as per inventory.

Table 224*A*.—Typical Equipment Water-bound Macadam Roads

Local stone. 5 miles per season

Equipment item	Approximate first cost 1926	Yearly depreciation, interest, repair, taxes, etc.
Grading equipment (p. 1126)..	$ 8,000 to $30,000	$ 2,000 to $11,000
Air compressor and drill outfit	to 3,000	to 1,200
Crushing outfit..............	5,000 to 6,000	1,200 to 1,500
Pumping outfit..............	800 to 1,500	200 to 500
Pipe line, 4 miles ±..........	3,000 to 5,000	1,500 to 2,000
Roller (included in grading equip.)...................		
Wagons or trucks[1]...........	1,500 to 10,000	1,000 to 5,000
Small tools..................	500 to 1,000	500 to 1,000
Totals.....................	$18,800 to $56,500	$6,400 to $22,200
Moving plant on job.........	....	1,000 to 2,000
Total yearly...............	....	$ 7,500 to $24,000
Approximate per mile.......	....	1,500 to 5,000
Approximate per cubic yard macadam[2]..............	....	0.50 to 1.20

[1] Hauling often sublet.
[2] Based on 18′ road 12″ deep (grading overhead not included).
Note.—Quarry outfit not needed if boulder stone is used.

TABLE 224*B*.—TYPICAL EQUIPMENT WATER-BOUND MACADAM

Imported stone. 5 miles per season

Equipment item	Approximate first cost 1926	Approximate yearly depreciation, repairs, interest, taxes, etc.
Grading equipment (p. 1126)	$ 8,000 to $30,000	$2,000 to $11,000
Elevator or crane unloader and storage bin	2,000 to 10,000	500 to 2,500
Pumping outfit	800 to 1,500	200 to 500
Pipe line	3,000 to 5,000	1,500 to 2,000
Wagons or trucks[1]	1,500 to 10,000	1,000 to 5,000
Small tools	400 to 800	400 to 800
Totals	$16,000 to $57,000	$5,600 to $21,800
Moving plant on job		500 to 1,000
Total yearly		$6,100 to $23,000
Approximate per mile		1,200 to 4,600
Approximate per cubic yard macadam[2]		0.40 to 1.00

[1] Hauling often sublet.
[2] Based on 3500 cu. yd. per mile (grading overhead not included).

TABLE 224*C*.—TYPICAL EQUIPMENT BITUMINOUS MACADAM

Local stone. 5 miles per season

Equipment item	Approximate first cost 1926	Approximate yearly depreciation, repairs, interest, etc.
Grading equipment (p. 1126)	$ 8,000 to $30,000	$2,000 to $11,000
Air compressor and drill outfit	to 3,000	to 1,200
Crushing outfit	5,000 to 6,000	1,200 to 1,500
Wagons or trucks[1]	1,500 to 10,000	1,000 to 5,000
Pressure distributor[2]	to 9,000	to 4,000
Small tools	500 to 1,000	500 to 1,000
Totals	$15,000 to $59,000	$4,700 to 23,700
Moving plant on job		1,000 to 2,000
Yearly total		$6,000 to $26,000
Approximate per mile		1,200 to 5,000
Approximate per cubic yard macadam[3]		0.35 to 1.20

[1] Often sublet.
[2] Generally sublet.
[3] Based on 3500 cu. yd. per mile (grading overhead not included).

ABLE 224*D*.—TYPICAL EQUIPMENT BITUMINOUS MACADAM
Imported stone. 5 miles per season

Equipment item	Approximate first cost 1926	Approximate yearly depreciation, repairs, interest, etc.
Grading equipment (p. 1126)...	$ 8,000 to $30,000	$2,000 to $11,000
Unloading outfit..............	2,000 to 10,000	500 to 2,500
Wagons or trucks[1]............	1,500 to 10,000	1,000 to 5,000
Pressure distributor[2]...........	to 9,000	to 4,000
Small tools..................	500 to 1,000	500 to 1,000
Totals....................	$12,000 to $60,000	$4,000 to $23,500
Moving plant on job..........	....	800 to 1,500
Yearly total................	....	$5,000 to 25,000
Approximate per mile........	....	1,000 to 5,000
Approximate per cubic yard macadam[3]...............	....	0.30 to 1.10

[1] Often sublet.
[2] Generally sublet.
[3] Based on 17,000 cu. yd. per season (grading overhead not included).

ABLE 224*E*.—TYPICAL EQUIPMENT CEMENT-CONCRETE PAVEMENTS AND BASES
Imported materials

Equipment item	Approximate first cost 1926	Yearly depreciation, interest, repairs, etc.
Grading equipment (p. 1126)..	$ 8,000 to $30,000	$ 2,000 to $11,000
Concrete equipment (p. 1144).	21,000 to 38,000	11,000 to 20,000
Totals....................	$29,000 to $68,000	$13,000 to 31,000
Moving plant on job.........	....	1,000 to 2,000
Yearly total...............	....	$14,000 to $33,000
Approximate overhead per cubic yard concrete based on 15,000 cu. yd. per year. Grading overhead not included...............	....	0.90 to 2.00

NOTE.—Where local materials are required, use items from Table 224*A* r production of local material product and eliminate special car unloading uipment.

TABLE 224*F*.—TYPICAL EQUIPMENT BITUMINOUS CONCRE SURFACE COATS

Topeka and sheet asphalt. 100 to 150 tons daily outpu

Equipment item	Approximate first cost 1926	Yearly depreciatio interest, repair, et
Portable car plant	$20,000 to $30,000	$ 8,000 to $12,00
Elevator or crane unloader and bin	3,000 to 10,000	800 to 2,50
Trucks[1]	to 30,000	to 15,00
Tandem roller	3,000 to 4,000	600 to 80
Small tools	500 to 1,000	500 to 1,00
Total	$27,000 to $75,000	$10,000 to $31,00
Moving	....	500 to 1,00
Total yearly	....	$10,500 to $32,00
Approximate per ton of mix[2]	....	0.70 to 2.1

[1] Hauling often sublet which materially reduces initial investment.
[2] Based on 15,000 tons seasons output.

TABLE 224*G*.—TYPICAL EQUIPMENT SMALL-SPAN BRIDGE CO TRACTS

Equipment item	Approximate first cost 1926	Yearly deprecia tion, interest, repair, etc.
Truck clam-shell crane for unloading materials, steel, stone, sand, etc., and for foundation excavation	$ —— to $ 9,000	—— to $2,50
Pile-driving outfit, drop hammer or steam hammer	1,500 to 3,000	400 to 800
Pumping outfit	200 to 1,000	50 to 250
Small tractor	to 1,000	to 300
One-bag batch concrete mixer	700 to 1,000	350 to 500
Trucks or wagons[1]	to 3,000	to 2,000
Air compressor, drill, and riveting outfit	to 3,000	to 1,200
Small tools	300 to 500	300 to 500
Totals	$3,000 to $22,000	$1,100 to $8,00
Moving plant on job	....	200 to 500

[1] Distributed over season's work which generally amounts to about 6 10% of the contract amount.
[2] Hauling generally sublet on small jobs.

NEW YORK STATE (CEMENT CONCRETE PAVEMENT)

Length, miles	Width, feet	Thickness, inches	Mix	Reinforcement	Cubic yard price[1]
erkimer County, Highway 8239, Cold Brook—Nobleboro					
8.23	18	7-6-7	1: 1½: 3	Marginal bars	$7.00
lleghany County, Road 8236, Cuba—Black Creek, Route 2					
2.30	18	7-6-7	1:1½:3	Marginal bars	$8.50
Broome County, Repair Contract 3126, Kirkwood					
2	18	7-6-7	1 :1½: 3	40 mesh and area bars	$9.00
attaragus County, Road 1713, Pennsylvania State Line—Portville					
1.91	18	8-7-8	1: ½: 3	Marginal bars	$7.50
Chenango County, Road 8216, Coventryville—Bambridge					
6.78	18	7-6-7	1: 1½: 3	Marginal bars	$8.00
Columbia County, Road 1753, Stuyvesant—Castleton					
5.42	18	8-7-8	1: 1½: 3	Marginal bars	$7.80

[1] Cement and reinforcement not included.

New Jersey State

Length, miles	Width, feet	Thickness, inches	Mix	Reinforcement	Square yard price
Atlantic County—Absecon, Route 3, Section 14					
1.78	29	8	1: 1¾: 3½	Single line	$2.75 including cement and reinforcement
Henderson County, State Route 9, White House—Lebano					
4	20-30	8	1:1 ¾: 3½	121 lb.	$3.20
Middlesex County, St. George Ave., State Route 4, Section 3					
4.01	29-50	9	1: 1¾: 3½	121 lb.	$3.20
Middlesex County, State Route 4, Section 25, South Ambo					
2.81	29-40	9	1: 1¾: 3½	121 lb.	$3.10
Monmouth County, Route 4, Section 4, Keyport Cutoff					
1.31	29	9	1: 1¾: 3½	121 lb.	$3.05
Morris County, Dover, Route 5, McFarland St.					
1.25	20-40	8	1:1¾:3½	121 lb.	$3.00

Connecticut State

Length, feet	Width, feet	Thickness, inches	Mix	Reinforcement	Cubic yard price[1]
Hartford County—E. Windsor					
1,650	18	8	1: 2: 3½	17.23 cu. yd.	$10.00
New Haven County, Middletown—Durham					
28,720	20	8	1: 2: 3½	15.74 cu. yd.	$8.20
Windham County, Willimantic—Putnam Road					
19,320	18	8	1: 2: 3½	17.23 cu. yd.	$8.43
Litchfield County, Torrington—Goshen Road					
7,492	20	8	1: 2: 3	Rods	$9.08
Middlesex County, East Hampton					
14,790	20	8	1: 2: 3	Rods	$10.00
New Haven County, Waterbury Turnpike					
21,975	20	8	1: 2: 3	Rods	7.43

[1] Cement and reinforcement not included.

PRICE BID TABULATION, NEW YORK, 1926

Item	Item	Unit	Number of bids	Maximum price bid	Minimum price bid	Average price bid
2	Earth excavation (roadway)	Cubic yard	30	$ 1.65	$ 0.25	$ 0.62
3	Rock excavation (roadway)	Cubic yard	30	4.40	0.30	2.49
4	Unclassified excavation (roadway)	Cubic yard	30	2.50	0.25	0.82
5	Overhaul	Station yard	30	0.005	0.001	0.0048
6	Sewer pipe:					
	10″ pipe (exclusive of excavation)	Lineal foot	30	1.00	0.60	0.85
	12″ pipe (exclusive of excavation)	Lineal foot	30	1.25	0.60	0.87
	15″ pipe	Lineal foot	21	1.50	0.96	1.31
	18″ pipe	Lineal foot	30	2.25	1.00	1.63
	20″ pipe	Lineal foot	21	2.75	1.70	2.23
	24″ pipe	Lineal foot	22	3.75	2.05	2.95
7	Pipe underdrain:					
	3″ drain	Lineal foot	11	0.20	0.07	0.18
	4″ drain	Lineal foot	30	0.30	0.15	0.24
	6″ drain	Lineal foot	30	0.40	0.18	0.30
13	Cast-iron pipe:					
	12″ pipe	Lineal foot	30	3.75	2.50	3.67
	16″ pipe	Lineal foot	30	4.00	1.00	3.71
	18″ pipe	Lineal foot	30	5.00	4.00	4.86
	20″ pipe	Lineal foot	30	6.25	5.00	5.67
	24″ pipe	Lineal foot	30	8.00	6.25	7.89
14	Reinforced-concrete pipe:					
	12″ pipe	Lineal foot	30	1.95	1.00	1.77
	15″ pipe	Lineal foot	30	2.50	1.50	2.06
	18″ pipe	Lineal foot	30	3.00	1.85	2.26
	24″ pipe	Lineal foot	30	4.00	2.75	3.56
	30″ pipe	Lineal foot	10	4.90	4.00	4.73
	36″ pipe (exclusive of excavation)	Lineal foot	16	6.50	6.00	6.03
15[1]	Portland cement	Barrels	30	4.00	2.60	2.85
[illegible]	[illegible]	Cubic yard	[illegible]	26.50	0.65	10.25

17	Cement concrete for parapets, 1: 2: 3½ mix	Cubic yard	[illegible]	[illegible]	[illegible]	[illegible]
18[1]	Cement concrete for parapets, 1: 1½: 3 mix	Cubic yard				
19[1]	Cement concrete for balustrades, 1: 1½: 3 mix	Cubic yard				
20[1]	First-class concrete, 1: 2: 4 mix	Cubic yard	458	27.50	10.00	18.60
21[1]	Second-class concrete, 1: 2½: 5 mix	Cubic yard	211	23.00	6.00	14.83
24	Medina sandstone or granite curb	Lineal foot				
25	Sandstone or bluestone curb	Lineal foot				
26	Resetting old curbing	Lineal foot	5	0.99	0.50	0.86
27*a*	Concrete curbing Type A	Lineal foot	30	1.00	0.70	0.86
27*b*	Concrete curbing Type B	Lineal foot	11	1.25	1.10	1.22
28	Concrete gutters	Square yard	30	2.50	1.00	1.79
29	Cobble gutters, cement joints	Square yard	30	1.25	0.80	1.06
30	Metal reinforcement for concrete pavement	Square yard	724	0.45	0.20	0.31
31	Bar reinforcement for concrete pavement	Pound	312	0.05	0.03	0.04
32	Steel fabric reinforcement for culverts	Square foot	888	0.30	0.10	0.20
32*A*	Bar reinforcement for structures	Pound	840	0.10	0.04	0.07
32*B*	Structural steel	Pound	260	0.08	0.04	0.06
33	Miscellaneous iron and steel	Pound	30	0.10	0.06	0.09
34	Wooden guide railing	Lineal foot				
35	Cable guide railing	Lineal foot	30	1.50	0.70	1.02
36	Concrete guide posts	Each	30	3.25	2.00	3.02
37	Pipe railing	Lineal foot				
41	Field or quarry stone, bottom course	Cubic yard	30	4.73	1.00	3.06
42	Run of bank gravel, bottom course	Cubic yard	30	2.50	1.20	2.02
43	Screened gravel, bottom course	Cubic yard				
43*A*	Screened gravel, loose measure, bottom course	Cubic yard				
44	Broken slag, bottom course	Cubic yard	14	6.25	4.25	4.53
44*A*	Broken slag, loose measure, bottom course	Cubic yard				
45	Broken stone, bottom course	Cubic yard	6	5.85	5.00	5.23
45*A*	Broken stone, loose measure, bottom course	Cubic yard	30	4.20	3.00	3.91
46[1]	Concrete foundation for pavement	Cubic yard	19	10.25	6.95	8.97
47[2]	Bituminous-macadam penetration method	Cubic yard	6	7.50	6.00	6.74
48[2]	Asphaltic concrete					
49[2]	Bituminous-macadam mixing method, Type 2	Square yard	19	1.23	0.70	0.90
50[2]	Binder course, bituminous-macadam mixing method	Ton	4	10.00	7.00	8.31
51*A*[1]	Cement-concrete pavement	Cubic yard				
51*B*[1]	Cement-concrete pavement	Cubic yard	30	10.55	7.00	8.40
51*C*[1]	Cement-concrete pavement	Cubic yard	30	9.75	6.00	7.89
51*D*[1]	Cement-concrete pavement	Cubic yard	30	20.00	6.00	9.86
52	Wood-block pavement	Square yard				

PRICE BID TABULATION, NEW YORK, 1926—*Continued*

Item	Item	Unit	Number of bids	Maximum price bid	Minimum price bid	Average price bid
53	Asphaltic-block pavement, approved trap rock	Square yard				
53A	Asphaltic-block pavement, approved limestone	Square yard				
54	Brick pavement, Type 1	Square yard				
54A	Brick pavement, Type 2	Square yard				
55	Stone-block pavement, Type 1	Square yard				
55A	Stone-block pavement, Type 2	Square yard				
56	Trimming shoulders	Square foot	30	$ 0.20	$ 0.05	$ 0.11
60	Treatment with bituminous material	Square foot				
60A	Bituminous material waterproofing	Square foot	30	0.12	0.06	0.10
80	Rip-rap	Cubic yard	30	4.00	2.40	3.50
81	Timber and lumber	M ft B.M. board measure	30	80.00	1.00	39.60
84	Timber piles	Lineal foot	30	1.00	0.23	0.90
85	Cast-in-place concrete piles	Lineal foot				
87	Test piles	Each	30	100.00	50.00	82.33
88	Loading piles	Each				

[1] Cement not included.
[2] Bitumen not included.

CHAPTER XVI

NOTES ON CONSTRUCTION

No matter how well a road is designed, unless the construction engineer uses good judgment, and the inspection is conscientious and intelligent, the results will not be satisfactory. This chapter emphasizes the importance of the different stages of the work and gives a few suggestions as to the manner of meeting common difficulties.

DUTIES AND AUTHORITY OF DIFFERENT UNITS OF THE USUAL ORGANIZATION

Inspectors.—Inspectors are responsible for the detail work of construction. They must be thoroughly familiar with the plans and specifications. They pass on the quality of materials delivered, correctness of grades, dimensions of work, and the quality of the workmanship as stipulated in the specifications.

Inspectors have no authority to change plans or specifications. They have authority to reject materials and to stop work which is not being properly done pending the decision of the field engineer. They report directly to the engineer in charge of field construction. Inspectors are really the most important men in the organization, if good work is desired. Good inspectors are hard to get, as the work is tedious and confining.

Field Engineers.—The field engineer is responsible for staking out the construction work, for monthly and final estimates, and for the efficiency of the inspectors. He must keep track of the amount of work done and materials used to see that the contract amounts are not exceeded. He checks all plans and quantities and notifies the chief engineer if changes are desirable.

The field engineer has no authority to change plans or specifications with the exception of minor corrections of mistakes or slight changes in grade and location to fit unexpected conditions, provided such changes do not increase quantities beyond the contract provisions. The field engineer reports directly to the division or chief engineer.

Executive Engineers.—The division or chief engineer is largely an executive. He makes the necessary assignments and has the power to make any necessary changes in the plans to meet unexpected conditions provided these changes do not exceed the contingent allowances of the contract. If required changes call for new items in the contract or for an increase in quantities beyond contingent allowances, he prepares the necessary supplementary contract agreements which must be aoproved by the contractor

and the financial control officer of the highway department before any such work is done.

Final acceptance of work lies with the head of the department or the civil boards authorizing the work.

Staking for Construction.—The construction survey picks up the center line shown on the plans and by means of offset stakes driven to a certain elevation marks the position and elevation of the road conveniently for building. Any arrangement of stakes that shows the position of the proposed center line and the elevation of the proposed grade is satisfactory. These stakes may be set on one or both sides of the road at intervals of 50 or 100′. The offsets to the center line may be marked to the nearest one-tenth foot,

Staking Out								Notes				
Sta.	Offsets		Cut or Fill		Levels				Grade	Grade Rod Reading	Rod Reading on Stakes	
	L.	R.	L.	R.	B.S.	F.S.	Elev.	H.I.	Elev.		L.	R.
B.M.5							526.42					
10	25	23	F0.5	F1.0	4.17			530.59	524.2	6.4	6.9	7.4
+50	25	22	F0.5	F1.5				"	524.6	6.0	6.5	7.5
11	24	25	F0.5	F1.5				"	525.0	5.6	6.1	7.1
+50	21	26	C0.5	F1.0				"	525.4	5.2	4.7	8.2
12	22	25	C0.5	F1.5				"	525.8	4.8	4.3	6.3
+50	23	24	C1.0	F2.0				"	526.2	4.4	3.4	6.4
13	24	24	Gr.	Gr				"	526.6	4.0	4.0	4.0
+50	25	23	Gr.	F0.5				"	527.0	3.6	3.6	4.1
14	30	17	Gr.	C0.5		3.20	527.39	"	527.8	2.8	2.8	2.3
+50	25	23	Gr	C1.0	7.41			534.80	528.6	6.2	6.2	5.2
15	25	23	C0.5	F1.5				"	529.4	5.4	4.9	6.9
+50	25	23	F1.0	F1.0				"	530.2	4.6	5.6	5.6
16	25	23	Gr.	C1.0				"	531.0	3.8	3.8	2.8
+50	25	23	F1.5	C1.0				"	531.8	3.0	4.5	2.0
17	24	24	F1.5	Gr.				"	532.6	2.2	3.7	2.2
+50	18	28	F1.0	F5.0				"	533.4	1.4	2.4	6.4
								"				

FIG. 329.—Staking out notes.

or the stakes may be set that the offset is an even foot and driven so that the elevation of the proposed grade is above or below them an even foot, half foot, or an odd tenth. A satisfactory method in general use in western New York is to set the construction stakes on both sides every 50′, with an even foot or half foot above or below grade.

Such stakes can be readily explained to the ordinary grading foreman so that he has no difficulty in working from them without the assistance of an inspector. The 50′ interval is convenient for fine grading, as the lines can be stretched this distance with no apparent sag, while if a 100′ interval is used, the sag is objectionable. With stakes on both sides of the road, the elevation of the proposed grade can be readily transferred to the center by stretching a line between them and measuring down or up the required amount. This is a much simpler and more accurate method than transferring by straight-edge where two or three lengths of straight-edge must be used from the stake to the center.

The left stake marked C 4.0′ offset 28.0′ means that the crown grade of the finished road is 4.0′ below the top of this stake and the proposed center line of macadam is 28.0′ from the face of the stake (see Fig. 330).

To transfer the proposed grade to the center line by the string method: Fasten chalk line to top of left stake; measure up 3.0′ above top of right stake and draw line taut at this elevation. The string is level and 4.0′ above crown grade. Pull as tight as possible, allow about ½″ for sag, and measure down 3′ 11½″ for finished grade.

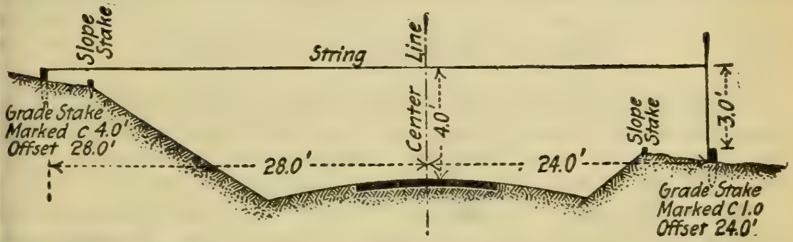


FIG. 330.—Showing suggested method of staking out.

Cost of Staking Out.—The speed and cost of staking at 50′ intervals will, of course, vary with the experience of the men and the character of the road. A party of four men should pick up the proposed center line and set offset stakes on both sides at a speed of 1.5 to 2 miles a day; a party of three men should grade these stakes at a speed of 1.0 to 2.0 miles a day, and the cost of staking out for construction, including livery and board, would be from $40 to $80 per mile 1925 cost conditions (livery $4 per day; board $3 per man per day and engineers $10 and assistants $4 to $6.

It is common for new men to spend an unnecessary amount of time in setting the grade stakes. They will often attempt to have the elevation of the grade stakes correct to within 0.01′. For all practical purposes, for work of this character, stakes correct to within 0.1′ in elevation and 0.1′ in alignment are satisfactory. Curb stakes for village work, however, should be carefully set to within 0.01′ in elevation and line. For such work line is marked by tacks in top of stake.

Culverts.—Culverts are usually constructed before the road is graded. They should be completed well in advance of the pavement, because even though the backfill is carefully tamped, there is bound to be some additional settlement under traffic action, and if the pavement is laid over a fresh backfill, depressions or cracks are sure to develop which, if not repaired, make "thank-you-marms" in the road or introduce areas of no soil support under rigid slabs which often produce cracks unless the pavement is thickened enough to bridge the trench. For extra depth of pavement bases over trenches, see page 417.

Cast-iron Pipe.—Trenches for pipe are dug the required depth, the bottom being made wide enough to allow the joints to be

properly calked. This requires a trench 18 to 24″ wider than the pipe diameter; *i.e.*, for a 12″ pipe the trench is 30 to 36″. Bell holes are dug as shown in Fig. 331, so that the pipe will have a uniform bearing its entire length. At no point should it rest directly on boulders or ledge rocks. If the foundation is soft, the pipe should be laid on a concrete or gravel base. For ordinary soils the only precaution the inspector need take is to prevent backfill under the pipe.

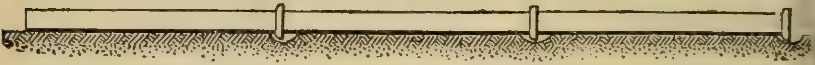


FIG. 331.—Bell holes for pipe trench.

Unless the foreman is alert, the trench is often excavated toc much in some places, which are then back filled. This is bad practice except where boulders are encountered which must be removed and the cavities backfilled with good material.

Pipe.—The pipe is inspected for flaws; it is then placed in the trench with the bell end upstream. At each joint the spigot enc is placed in the bell and forced against the shoulder, making a tight joint. The pipe is then lined correctly and a gasket of jute

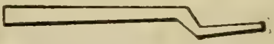


FIG. 332.—Steel joint caulking tool.

or oakum driven into the joint with an iron calking tool having a 2 to 3″ offset, as shown in Fig. 332. The balance of the joint is then filled with a 1:1 cement mortar.

The trench is then backfilled, care being taken not to throw the pipe out of line; the backfill must be well tamped in layers not exceeding 6″, heavy paver's rammers being used. A good working rule is to use two of the best men on the job tamping and the laziest man on the force throwing dirt to them.

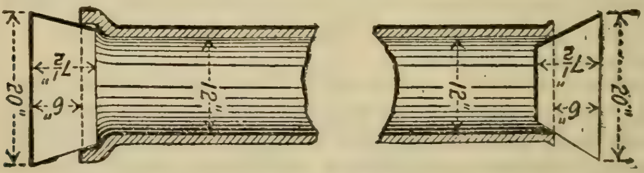


FIG. 333.—Headwall plug extension forms.

Headwalls for Culverts.—The face of the headwall should extend beyond the end of the pipe, as it is difficult to get a good-looking connection if it is flush with the end.

Figure 333 shows a convenient plug form for this extension This plug is set into the end of the pipe and can be readily removed the resulting headwall being pleasing in appearance. The headwal

form can, also, be readily skewed (set at an angle with the pipe) if required.

Reinforced-concrete Pipe.—Pipe of this character is laid in the same general manner as cast-iron pipe with the following minor changes. It is desirable to dig the trench 2 or 3″ lower than necessary and backfill with gravel well tamped to give a slightly flexible bed for the pipe. It is essential that concrete pipe be handled with care, as most of the damage to this pipe occurs by careless handling. Pipe up to 18″ in diameter can be easily handled by rope slings held by hand. For 24″ or larger pipe a tripod with chain hoist is desirable to prevent breakage in lowering into the trench and to avoid needless disturbance of the bed by dropping heavy pipe at an angle. The backfill for this kind of pipe must be very carefully done up to half height. In loam, clay, and quicksand soils, it is desirable to cradle the lower half of the pipe with concrete 1:3:6 mix (see Chap. IV p. 217).

CONCRETE CULVERTS

Excavation.—The trench is dug to the required depth; if the material will stand vertically, no back forms are necessary, and the width of the trench is made the width of the out-to-out dimensions of the culverts. If back forms are needed, the trench is usually made 2′ wider. If running water is encountered which cannot be temporarily dammed or diverted, the trench is made wide enough to flume the stream through on one side of the back forms for small culverts, or between the abutments for larger-span structures.

Backfill.—The backfill is made as for cast-iron pipe except that it should not be deposited on the fresh top of a culvert within 24 hr. of laying the concrete.

Forms.—Forms should be true to shape and constructed of planed tongue and groove or carefully sized lumber, for the exposed surfaces. Face form lumber should never be less than 1¼″ and preferably 2″ thick and should be well ribbed (see pp. 1346 to 1353 for typical forms). They should be water tight, as otherwise the fine material will run out of the face of the concrete and leave a rough "pop-corn" surface. They must be well braced to prevent bulging. Triangular or feather-edged grooved moldings are placed in the angles of the forms to shape them satisfactorily. The bottom boards of high thin side walls should be left loose until concrete is ready to pour to permit cleaning the foundation concrete of chips or dirt which always collect.

Removal of Forms.—The length of time that the forms should remain in place is a matter of judgment; it depends upon the cement and weather conditions.

The author's practice is as follows:

Headwalls or parapet forms are removed within 36 hr. in dry weather or within 48 hr. in damp, cold weather, in order to rub down the surfaces.

Low side-wall forms for spans of 2 to 3′, where the deck is constructed later, may be removed in 36 to 48 hr.

Trunk forms for small culverts 2 to 3′ span may be removed in from 3 to 7 days.

Trunk forms for medium culverts up to 10′ span, 7 to 14 days.

Deck forms for spans above 10′ may be removed in from 14 to 28 days.

Any unusual load, such as a roller, should not be allowed over a new culvert of even a small span in less than 7 days, unless precautions are taken to distribute the pressure by planking the backfill or otherwise; on the larger structures a time limit of 3 to 4 weeks is advisable.

MIXING AND PLACING CONCRETE

The strength of the concrete depends largely upon the thoroughness of the mixing and the water content.

The author's practice has been as follows:

Hand Mixing Cement and Sand.

3 turns dry for third-class concrete (foundations and side walls)

4 turns dry for second-class concrete (decks and parapets)

Add water and mix mortar.

Drench stone and turn stone and mortar:

3 times for third-class concrete.

4 times for second-class concrete.

Machine Mix.—Minimum 1 min. (15 revolutions).

Deposit in forms by dropping. Do not cast, as this separates the coarse and fine material. Use enough water to give a mixture that quakes like liver under the rammer (about 5 to 6 gal. per sack of cement).

Deposit in layers not over 6″ deep and ram each layer thoroughly spade the concrete thoroughly, and work an excess of the fine stuff to the face of the forms by prying the larger fragments back from the form with a narrow spade or broad-tined fork.

Machine Mixing.—Culverts generally contain such a small quantity of concrete that machine mixing is often not used although a small mixer is very convenient and the one-bag batch size is in very common use for work of this character. In case a batch mixer is employed, the inspection is simplified to checking the quantities of cement, sand, and stone in each charge, regulating the water content, and insisting on complete mix. Give at least a minute in the drum. If a continuous mixer is used, it is well to keep watch of the cement hopper, as the cement is liable to run low, feeding only a portion of the work, or a large lump of cement may ride on top of the worm and hinder the feed; or the worm may become coated with damp cement which reduces the capacity. If the inspector watches the cement hopper, the contractor will tend to the sand and stone hoppers. Continuous mixers are usually prohibited on account of the uncertainty of the resulting product.

Capacity of Concrete Mixers.—Using a minute mix, different-size mixers will turn out approximately the following amounts of 1:2:4 structural concrete: (20 to 30 batches per hour).

1-bag batch................	3 to 4 cu. yd. per hour
1½-bag batch..............	5 to 7 cu. yd. per hour
2-bag batch................	7 to 10 cu. yd. per hour

Finishing Concrete.—If a smooth, marble-like surface is desired, it can be obtained by rubbing down the surface before it has fully set with a cement-sand brick moistened with water. If a rough sandpaper-like finish is wanted, it can be secured by rubbing with a wooden float moistened with water. This finish is not so apt to hair check as the smooth finish. For a high-grade rub finish for more pretentious ornamental structures such as concrete arch bridges, parapets, etc., see specifications on page 1522.

Freshly laid concrete should be protected from a hot sun by covering it with canvas, or blankets, and wetting it down frequently for 4 or 5 days. No plastering of surfaces should be allowed after the cement has set. If, however, it has been badly hair checked from heat, the defect can usually be remedied by rubbing with a carborundum brick. Freshly laid concrete must be protected from frost. A satisfactory method is to cover with canvas and a thick layer of manure or straw. If the concrete has been frost pitted on the surface only, bush hammering will give a rough stone finish, pleasing in appearance. No culvert work should be allowed in continued cold weather, as it is difficult to get a good finish, and in roadwork there is no necessity of doing this work in the winter. *Concrete-culvert inspection must be continuous.*

Amounts of Material Required.—For the amounts of material required per cu. yd. of concrete, see page 1092.

Tables similar to 225 given below and computed for the standard designs in use in any locality are very convenient in placing materials for culvert construction. Table 225 is computed for culverts shown in Fig. 65, Chap. IV, page 221. 3rd class concrete sidewalls and bottom and wings—2nd class slabs and parapets.

NOTE.—*Amount of cement shown in Table 225 is based on* 1.3 *bbls. per c. y. 2nd class and* 1.1 *bbls. per c. y. 3rd class concrete. If culverts are constructed entirely of* 1:2:4 *mix take total c. y. of concrete shown for structure and multiply by* 1.6 *bbls. to get approx. amount of cement.*

TABLE 225.—CONCRETE CULVERTS

1.5′ high × 2.0′ wide							
Length Feet	Concrete Cubic Yards		Paving Square Yards	Ex. Met. Square Feet	Cement Barrels*	Sand Cubic Yards	Crushed Stone Cubic Yards
	Second	Third					
20	2.2	5.6	6.4	80	8.4	3.6	7.2
21	2.2	5.8	6.4	84	8.6	3.7	7.4
22	2.3	6.1	6.4	88	9.0	3.9	7.8
23	2.4	6.3	6.4	92	9.3	4.1	8.1
24	2.5	6.5	6.4	96	9.7	4.2	8.3
25	2.5	6.7	6.4	100	9.9	4.3	8.5
26	2.6	6.9	6.4	104	10.2	4.4	8.8
27	2.7	7.2	6.4	108	10.6	4.6	9.2
28	2.8	7.4	6.4	112	10.9	4.8	9.5
29	2.8	7.6	6.4	116	11.1	4.9	9.6
30	2.9	7.8	6.4	120	11.5	5.0	9.9
31	3.0	8.1	6.4	124	11.9	5.2	10.3
32	3.1	8.3	6.4	128	12.2	5.3	10.6
33	3.1	8.5	6.4	132	12.4	5.4	10.8
34	3.2	8.7	6.4	136	12.7	5.6	11.0
35	3.3	8.9	6.4	140	13.1	5.7	11.3
36	3.4	9.2	6.4	144	13.5	5.9	11.7
37	3.4	9.4	6.4	148	13.7	6.0	11.9
38	3.5	9.6	6.4	152	14.0	6.1	12.1
39	3.6	9.8	6.4	156	14.5	6.3	12.4
40	3.6	10.1	6.4	160	14.8	6.4	12.7
41	3.7	10.3	6.4	164	15.1	6.5	13.0
42	3.8	10.5	6.4	168	15.4	6.7	13.3
43	3.9	10.7	6.4	172	15.7	6.8	13.5
44	3.9	10.9	6.4	176	15.9	6.9	13.7
45	4.0	11.2	6.4	180	16.4	7.1	14.1
46	4.1	11.4	6.4	184	16.7	7.2	14.4
47	4.2	11.6	6.4	188	17.0	7.4	14.7
48	4.2	11.8	6.4	192	17.2	7.5	14.8
49	4.3	12.1	6.4	196	17.6	7.7	15.2
50	4.4	12.3	6.4	200	18.0	7.8	15.5

* See note page 1277.

TABLE 225.—*Continued*

2′ high × 2′ wide							
Length Feet	Concrete Cubic Yards		Expanded Metal Square Feet	Paving Square Yards	Portland Cement Barrels*	Sand Cubic Yards	Crushed Stone Cubic Yards
	Second	Third					
20	2.4	7.1	80	9.8	10.1	4.4	8.8
21	2.4	7.3	84	9.8	10.4	4.5	9.0
22	2.5	7.6	88	9.8	10.8	4.7	9.4
23	2.6	7.9	92	9.8	11.2	4.9	9.7
24	2.7	8.1	96	9.8	11.5	5.0	10.0
25	2.7	8.4	100	9.8	11.8	5.2	10.3
26	2.8	8.6	104	9.8	12.2	5.3	10.6
27	2.9	8.9	108	9.8	12.6	5.5	10.9
28	3.0	9.2	112	9.8	13.0	5.7	11.3
29	3.0	9.4	116	9.8	13.2	5.8	11.5
30	3.1	9.7	120	9.8	13.6	6.0	11.9
31	3.2	9.9	124	9.8	14.0	6.1	12.1
32	3.3	10.2	128	9.8	14.4	6.3	12.5
33	3.3	10.5	132	9.8	14.7	6.4	12.8
34	3.4	10.7	136	9.8	15.0	6.6	13.0
35	3.5	11.0	140	9.8	15.4	6.8	13.4
36	3.6	11.2	144	9.8	15.8	6.9	13.7
37	3.6	11.5	148	9.8	16.1	7.1	14.0
38	3.7	11.8	152	9.8	16.5	7.2	14.4
39	3.8	12.0	156	9.8	16.8	7.4	14.7
40	3.9	12.3	160	9.8	17.3	7.6	15.0
41	3.9	12.5	164	9.8	17.5	7.7	15.2
42	4.0	12.8	168	9.8	17.9	7.9	15.6
43	4.1	13.1	172	9.8	18.3	8.0	16.0
44	4.2	13.3	176	9.8	18.6	8.2	16.2
45	4.2	13.6	180	9.8	18.9	8.3	16.5
46	4.3	13.9	184	9.8	19.4	8.5	16.9
47	4.4	14.1	188	9.8	19.7	8.6	17.2
48	4.4	14.4	192	9.8	20.0	8.8	17.4
49	4.5	14.6	196	9.8	20.4	8.9	17.7
50	4.6	14.9	200	9.8	20.8	9.1	18.1

* See note page 1277.

TABLE 225.—*Continued*

2′ high × 3′ wide

Length Feet	Concrete Cubic Yards Second	Concrete Cubic Yards Third	Expended Metal Square Feet	Steel Pounds	Portland Cement Barrels*	Sand Cubic Yards	Crushed Stone Cubic Yards
20	2.3	7.6	100	78	10.5	4.6	9.2
21	2.4	7.9	105	81	11.0	4.8	9.6
22	2.5	8.2	110	85	11.4	5.0	9.9
23	2.6	8.5	115	88	11.8	5.2	10.3
24	2.6	8.8	120	91	12.1	5.3	10.6
25	2.7	9.1	125	95	12.5	5.5	10.9
26	2.8	9.4	130	98	13.0	5.7	11.3
27	2.9	9.7	135	101	13.4	5.9	11.7
28	3.0	9.9	140	105	13.7	6.0	12.0
29	3.1	10.2	145	108	14.1	6.2	12.3
30	3.2	10.5	150	112	14.6	6.4	12.7
31	3.3	10.8	155	115	15.0	6.6	13.1
32	3.4	11.1	160	118	15.4	6.8	13.4
33	3.5	11.4	165	122	15.9	7.0	13.8
34	3.6	11.7	170	125	16.3	7.2	14.2
35	3.7	12.0	175	128	16.7	7.3	14.6
36	3.8	12.2	180	132	17.0	7.5	14.8
37	3.9	12.5	185	135	17.5	7.7	15.2
38	3.9	12.8	190	139	17.8	7.8	15.5
39	4.0	13.1	195	142	18.2	8.0	15.9
40	4.1	13.4	200	145	18.6	8.2	16.2
41	4.2	13.7	205	149	19.0	8.4	16.6
42	4.3	14.0	210	152	19.5	8.6	17.0
43	4.4	14.3	215	156	19.9	8.7	17.3
44	4.5	14.5	220	159	20.2	8.9	17.6
45	4.6	14.8	225	162	20.7	9.1	18.0
46	4.7	15.1	230	166	21.1	9.2	18.4
47	4.8	15.4	235	169	21.5	9.4	18.7
48	4.9	15.7	240	172	21.9	9.6	19.1
49	5.0	16.0	245	176	22.4	9.8	19.5
50	5.1	16.3	250	179	22.8	10.0	19.8

* See note page 1277.

TABLE 225.—*Continued*

2′ high × 4′ wide							
Length Feet	Concrete Cubic Yards		Expanded Metal Square Feet	Steel Pounds	Portland Cement Barrels*	Sand Cubic Yards	Crushed Stone Cubic Yards
	Second	Third					
20	2.7	8.4	120	78	11.8	5.2	10.3
21	2.8	8.7	126	81	12.3	5.3	10.7
22	2.9	9.0	132	85	12.7	5.6	11.0
23	3.1	9.3	138	88	13.2	5.8	11.5
24	3.2	9.7	144	91	13.8	6.0	12.0
25	3.3	10.0	150	95	14.2	6.2	12.3
26	3.4	10.3	156	98	14.6	6.4	12.7
27	3.5	10.6	162	101	15.0	6.6	13.1
28	3.6	10.9	168	105	15.5	6.8	13.4
29	3.7	11.2	174	108	15.9	6.9	13.8
30	3.8	11.5	180	112	16.3	7.1	14.2
31	3.9	11.9	186	115	16.8	7.4	14.6
32	4.0	12.2	192	118	17.3	7.6	15.0
33	4.2	12.5	198	122	17.8	7.8	15.5
34	4.3	12.8	204	125	18.3	8.0	15.9
35	4.4	13.1	210	128	18.7	8.2	16.2
36	4.5	13.4	216	132	19.1	8.4	16.6
37	4.6	13.8	222	135	19.6	8.6	17.1
38	4.7	14.1	228	139	20.1	8.7	17.4
39	4.8	14.4	234	142	20.5	9.0	17.8
40	4.9	14.7	240	145	20.9	9.1	18.2
41	5.0	15.0	246	149	21.4	9.4	18.6
42	5.2	15.3	252	152	21.9	9.6	19.1
43	5.3	15.6	258	156	22.3	9.8	19.4
44	5.4	16.0	264	159	22.9	10.0	19.9
45	5.5	16.3	270	162	23.3	10.2	20.2
46	5.6	16.6	276	166	23.7	10.4	20.6
47	5.7	16.9	282	169	24.1	10.6	21.0
48	5.8	17.2	288	172	24.6	10.8	21.3
49	5.9	17.5	294	176	25.0	10.9	21.7
50	6.0	17.8	300	179	25.4	11.1	22.1

* See note page 1277.

TABLE 225.—*Continued*

3′ high × 3′ wide							
Length Feet	Concrete Cubic Yards		Expanded Metal Square Feet	Steel Pounds	Portland Cement Barrels*	Sand Cubic Yards	Crushed Stone Cubic Yards
	Second	Third					
20	2.3	10.4	100	82	13.4	5.9	11.8
21	2.4	10.8	105	85	13.9	6.2	12.3
22	2.5	11.2	110	88	14.4	6.4	12.7
23	2.6	11.5	115	92	14.9	6.6	13.1
24	2.6	11.9	120	95	15.3	6.8	13.5
25	2.7	12.2	125	99	15.7	7.0	13.8
26	2.8	12.6	130	102	16.2	7.2	14.3
27	2.9	13.0	135	105	16.8	7.4	14.8
28	3.0	13.3	140	109	17.2	7.6	15.1
29	3.1	13.7	145	112	17.7	7.9	15.6
30	3.2	14.0	150	116	18.2	8.1	16.0
31	3.3	14.4	155	119	18.7	8.3	16.4
32	3.4	14.8	160	122	19.2	8.5	16.9
33	3.5	15.1	165	126	19.6	8.7	17.3
34	3.6	15.5	170	129	20.2	8.9	17.6
35	3.7	15.8	175	133	20.6	9.1	18.1
36	3.8	16.2	180	136	21.1	9.4	18.6
37	3.9	16.6	185	139	21.6	9.6	19.0
38	3.9	16.9	190	143	22.0	9.7	19.3
39	4.0	17.3	195	146	22.5	10.0	19.8
40	4.1	17.6	200	150	22.9	10.2	20.1
41	4.2	18.0	205	153	23.4	10.4	20.6
42	4.3	18.4	210	156	24.0	10.6	21.1
43	4.4	18.7	215	160	24.4	10.8	21.4
44	4.5	19.1	220	163	24.9	11.0	21.9
45	4.6	19.4	225	167	25.4	11.2	22.3
46	4.7	19.8	230	170	25.9	11.4	22.7
47	4.8	20.2	235	173	26.4	11.7	23.2
48	4.9	20.5	240	177	26.8	11.9	23.6
49	5.0	20.9	245	180	27.4	12.1	24.0
50	5.1	21.2	250	184	27.8	12.3	24.4

* See note page 1277.

TABLE 225.—*Continued*

3′ high × 4′ wide							
Length Feet	Concrete Cubic Yards		Expanded Metal Square Feet	Steel Pounds	Portland Cement Barrels*	Sand Cubic Yards	Crushed Stone Cubic Yards
	Second	Third					
20	2.7	11.3	120	82	14.8	6.5	13.0
21	2.8	11.7	126	85	15.3	6.8	13.5
22	2.9	12.1	132	88	15.8	7.0	13.9
23	3.1	12.5	138	92	16.5	7.3	14.5
24	3.2	12.9	144	95	17.0	7.5	14.9
25	3.3	13.2	150	99	17.4	7.7	15.3
26	3.4	13.6	156	102	18.0	7.9	15.8
27	3.5	14.0	162	105	18.5	8.2	16.3
28	3.6	14.4	168	109	19.0	8.4	16.7
29	3.7	14.8	174	112	19.6	8.7	17.2
30	3.8	15.2	180	116	20.1	8.9	17.6
31	3.9	15.6	186	119	20.6	9.1	18.1
32	4.0	16.0	192	122	21.1	9.4	18.6
33	4.2	16.4	198	126	21.8	9.6	19.1
34	4.3	16.8	204	129	22.3	9.8	19.6
35	4.4	17.1	210	133	22.8	10.1	20.0
36	4.5	17.5	216	136	23.3	10.3	20.4
37	4.6	17.9	222	139	23.8	10.5	20.9
38	4.7	18.3	228	143	24.3	10.8	21.3
39	4.8	18.7	234	146	24.9	11.0	21.8
40	4.9	19.1	240	150	25.4	11.2	22.3
41	5.0	19.5	246	153	25.9	11.4	22.7
42	5.1	19.9	252	156	26.5	11.7	23.2
43	5.3	20.3	258	160	27.1	12.0	23.7
44	5.4	20.7	264	163	27.7	12.2	24.2
45	5.5	21.0	270	167	28.1	12.4	24.6
46	5.6	21.4	276	170	28.6	12.6	25.0
47	5.7	21.8	282	173	29.1	12.9	25.5
48	5.8	22.2	288	177	29.7	13.1	26.0
49	5.9	22.6	294	180	30.2	13.3	26.4
50	6.0	23.0	300	184	30.7	13.6	26.9

* See note page 1277.

TABLE 225.—*Continued*

4′ high × 4′ wide							
Length Feet	Concrete Cubic Yards		Expanded Metal Square Feet	Steel Pounds	Portland Cement Barrels*	Sand Cubic Yards	Crushed Stone Cubic Yards
	Second	Third					
20	2.7	14.5	120	87	18.1	8.1	15.9
21	2.8	15.0	126	90	18.7	8.3	16.5
22	2.9	15.4	132	94	19.2	8.6	17.0
23	3.1	15.9	138	97	20.0	8.9	17.6
24	3.2	16.4	144	100	20.6	9.2	18.2
25	3.3	16.8	150	104	21.1	9.4	18.7
26	3.4	17.3	156	107	21.8	9.7	19.2
27	3.5	17.7	162	111	22.3	9.9	19.7
28	3.6	18.2	168	114	22.9	10.2	20.2
29	3.7	18.7	174	117	23.5	10.5	20.8
30	3.8	19.1	180	121	24.1	10.7	21.2
31	3.9	19.6	186	124	24.7	11.0	21.8
32	4.0	20.1	192	128	25.3	11.3	22.4
33	4.2	20.5	198	131	26.0	11.6	22.9
34	4.3	21.0	204	134	26.6	11.9	23.5
35	4.4	21.4	210	138	27.1	12.1	24.0
36	4.5	21.9	216	141	27.8	12.4	24.5
37	4.6	22.4	222	145	28.4	12.6	25.1
38	4.7	22.8	228	148	28.9	12.9	25.5
39	4.8	23.3	234	151	29.6	13.1	26.1
40	4.9	23.8	240	155	30.2	13.4	26.6
41	5.0	24.2	246	158	30.7	13.7	27.1
42	5.1	24.7	252	162	31.4	14.0	27.7
43	5.3	25.2	258	165	32.1	14.3	28.3
44	5.4	25.6	264	168	32.6	14.5	28.8
45	5.5	26.1	270	172	33.3	14.8	29.3
46	5.6	26.5	276	175	33.8	15.0	29.8
47	5.7	27.0	282	179	34.4	15.3	30.3
48	5.8	27.5	288	182	35.1	15.6	30.9
49	5.9	27.9	294	185	35.6	15.8	31.4
50	6.0	28.4	300	189	36.2	16.1	31.9

* See note page 1277.

TABLE 225.—*Continued*

3′ high × 5′ wide							
Length Feet	Concrete Cubic Yards		Expanded Metal Square Feet	Steel Pounds	Portland Cement Barrels*	Sand Cubic Yards	Crushed Stone Cubic Yards
	Second	Third					
20	4.0	12.4	140	83	17.5	7.7	15.2
21	4.2	12.8	147	86	18.1	7.9	15.7
22	4.4	13.3	154	90	18.9	8.3	16.4
23	4.6	13.7	161	93	19.5	8.6	17.0
24	4.7	14.1	168	96	20.1	8.8	17.4
25	4.9	14.5	175	100	20.7	9.1	18.0
26	5.1	14.9	182	103	21.4	9.3	18.5
27	5.3	15.4	189	106	22.1	9.6	19.2
28	5.4	15.8	196	110	22.6	9.9	19.7
29	5.6	16.2	203	113	23.3	10.2	20.2
30	5.8	16.6	210	117	23.9	10.5	20.8
31	5.9	17.0	217	120	24.5	10.7	21.2
32	6.1	17.4	224	123	25.1	11.0	21.8
33	6.3	17.9	231	127	25.9	11.3	22.4
34	6.5	18.3	238	130	26.5	11.6	23.0
35	6.6	18.7	245	134	27.1	11.8	23.5
36	6.8	19.1	252	137	27.7	12.1	24.0
37	7.0	19.5	259	140	28.4	12.4	24.6
38	7.2	19.9	266	144	29.0	12.7	25.1
39	7.3	20.4	273	147	29.6	12.9	25.7
40	7.5	20.8	280	150	30.3	13.2	26.2
41	7.7	21.2	287	154	30.9	13.5	26.8
42	7.8	21.6	294	157	31.5	13.7	27.3
43	8.0	22.0	301	161	32.1	14.0	27.8
44	8.2	22.4	308	164	32.8	14.3	28.4
45	8.4	22.9	315	167	33.4	14.6	29.0
46	8.5	23.3	322	171	34.1	14.8	29.5
47	8.7	23.7	329	174	34.7	15.1	30.0
48	8.9	24.1	336	177	35.3	15.3	30.6
49	9.1	24.5	343	181	36.0	15.6	31.2
50	9.2	24.9	350	184	36.5	15.9	31.6

* See note page 1277.

TABLE 225.—*Continued*

4′ high × 5′ wide							
Length Feet	Concrete Cubic Yards		Expanded Metal Square Feet	Steel Pounds	Portland Cement Barrels*	Sand Cubic Yards	Crushed Stone Cubic Yards
	Second	Third					
20	4.0	15.8	140	88	21.0	9.2	18.4
21	4.2	16.3	147	92	21.7	9.6	19.0
22	4.4	16.8	154	95	22.5	9.9	19.7
23	4.6	17.2	161	99	23.1	10.2	20.2
24	4.7	17.7	168	102	23.7	10.5	20.8
25	4.9	18.2	175	105	24.5	10.8	21.4
26	5.1	18.7	182	109	25.2	11.1	22.1
27	5.3	19.2	189	112	26.0	11.5	22.7
28	5.4	19.7	196	116	26.6	11.7	23.3
29	5.6	20.2	203	119	27.4	12.1	23.9
30	5.8	20.7	210	122	28.1	12.4	24.6
31	5.9	21.2	217	126	28.8	12.7	25.1
32	6.1	21.7	224	129	29.5	13.0	25.8
33	6.3	22.1	231	133	30.2	13.3	26.3
34	6.5	22.6	238	136	30.9	13.6	27.0
35	6.6	23.1	245	139	31.5	13.9	27.6
36	6.8	23.6	252	143	32.3	14.2	28.2
37	7.0	24.1	259	146	33.0	14.5	28.8
38	7.2	24.6	266	150	33.8	14.9	29.5
39	7.3	25.1	273	153	34.4	15.1	30.1
40	7.5	25.6	280	156	35.2	15.5	30.7
41	7.7	26.1	287	160	35.9	15.8	31.3
42	7.8	26.6	294	163	36.6	16.1	31.9
43	8.0	27.0	301	167	37.2	16.4	32.5
44	8.2	27.5	308	170	38.0	16.7	33.1
45	8.4	28.0	315	173	38.7	17.0	33.8
46	8.5	28.5	322	177	39.3	17.3	34.3
47	8.7	29.0	329	180	40.1	17.6	35.0
48	8.9	29.5	336	184	40.9	18.0	35.6
49	9.1	30.0	343	187	41.6	18.3	36.3
50	9.2	30.5	350	190	42.2	18.6	36.8

* See note page 1277.

TABLE 225.—*Concluded*

5′ high × 5′ wide							
Length Feet	Concrete Cubic Yards		Expanded Metal Square Feet	Steel Pounds	Portland Cement Barrels*	Sand Cubic Yards	Crushed Stone Cubic Yards
	Second	Third					
20	4.0	19.5	140	93	24.7	11.0	21.8
21	4.2	20.0	147	96	25.5	11.3	22.5
22	4.4	20.6	154	100	26.3	11.7	23.2
23	4.6	21.2	161	103	27.2	12.1	24.2
24	4.7	21.7	168	106	27.8	12.4	24.8
25	4.9	22.3	175	110	28.7	12.7	25.4
26	5.1	22.9	182	113	29.5	13.1	26.2
27	5.3	23.4	189	117	30.3	13.4	26.8
28	5.4	24.0	196	120	31.0	13.8	27.6
29	5.6	24.6	203	123	31.9	14.1	28.2
30	5.8	25.1	210	127	32.6	14.5	29.0
31	5.9	25.7	217	130	33.4	14.8	29.6
32	6.1	26.2	224	134	34.1	15.1	30.2
33	6.3	26.8	231	137	35.0	15.5	31.0
34	6.5	27.4	238	140	35.8	15.9	31.8
35	6.6	27.9	245	144	36.4	16.2	32.4
36	6.8	28.5	252	147	37.3	16.5	33.0
37	7.0	29.1	259	150	38.2	16.9	33.8
38	7.2	29.6	266	154	38.9	17.2	34.4
39	7.3	30.2	273	157	39.6	17.6	35.1
40	7.5	30.8	280	161	40.5	17.9	35.8
41	7.7	31.3	287	164	41.2	18.3	36.5
42	7.8	31.9	294	167	42.0	18.6	37.2
43	8.0	32.5	301	171	42.8	19.0	37.9
44	8.2	33.0	308	174	43.6	19.3	38.6
45	8.4	33.6	315	178	44.4	19.7	39.3
46	8.5	34.2	322	181	45.2	20.0	40.0
47	8.7	34.7	329	184	45.9	20.3	40.6
48	8.9	35.2	336	188	46.7	20.6	41.2
49	9.1	35.9	343	191	47.6	21.0	42.0
50	9.2	36.4	350	195	48.3	21.4	42.8

* See note page 1277.

GRADING INSPECTION

Rough Grading.—Rough grading means all of the work preliminary to the finished shaping, and includes moving practically al the dirt that is to be handled. It is particularly important tc supervise this stage of construction, as it is here that the constructing engineer regulates the placing of the best material in the cente (under the metalling) and the poorest material on the sides.

In order to grade economically, the contractor and inspecto should each be furnished with lists similar to those given below (Fig 334), showing, in a convenient form, the amount of excavatio

Excavation Summary / **Lists**

Sta.	to Sta.	Exc.	Emb.	Waste	Borrow	Remarks
123	134	476	375			Quantities in cu. yds.
134	140	286	240			
140	157	642	662		185	Haul from Sta. 179 to 150
157	178	766	629			
178	179	231		231		
179	186	298	244			

Detail Quantities

Sta.	to Sta.	Exc.	Emb.	Remarks
123	123+50	575	225	Quantities in cu. ft.
123+50	124	150	900	
124	124+50	—	1450	
124+50	125	150	900	
125	125+50	320	200	
125+50	126	170	500	
126	126+50	30	925	
126+50	127	30	850	
127	127+50	260	410	
127+50	128	350	250	
128	128+50	635	160	
128+50	129	635	75	

FIG. 334.—Grading quantities.

station by station and within what bounds it is to be placed, or mass diagram can be prepared as explained on page 997.

Cuts.—For cuts over 3′ deep, slope stakes are placed and car taken that the slopes are properly carried down. If excavate beyond the finished lines, it is practically impossible to make a back fill that will hold, and the resulting irregularities are unsightly This is impossible where a steam shovel is used, in which case th slope is cut to the half-slope line and the upper earth plowed dow to complete the lower portion in fill.

Fills.—For fill slope, stakes are set in the same manner as fo cuts.[1] The earth should be deposited in thin layers, 6 to 8″ deep extending from slope to slope, and each layer well compacte

[1] Slope stakes can be located directly from the templet cross-sectio which is a much easier method than the railroad practice of rod and leve computation.

ither with a roller or by driving over it with wagons in the process ›f building. Where the old surface has a steep slope, it must be ›lowed to give a good bond with the new fill and prevent slide.

It is bad practice to build the center of the fill and then shovel oose material off of the edge to widen the slopes, as this loose side-ill is not compacted and under the action of frost will nearly always lough away from the harder central portion.

To get the full benefit of the teaming in compacting the dirt, a leep fill should be started at a point nearest the cut from which the naterial is hauled and each load driven over the loose layer. In his way nearly every fill can be better compacted than by the use

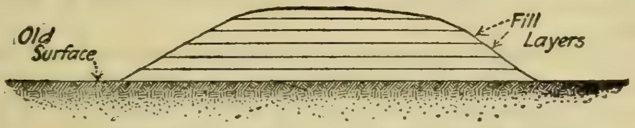


FIG. 335.—Fills land in layers.

›f a roller alone. For long fills where there is considerable team-ng over each layer, a roller is not usually needed.

Wet clay or heavy loam should never be placed in the bottom of ı fill, as it dries slowly when not in contact with the air and keeps he fill "spongy." The writer has seen cases where fills not over ₃′ deep have remained soft for 2 months where wet material had een used, and it was finally necessary to remove it.

For shallow fills 6″ or less in depth, the underlying hard roadbed nust be plowed or scarified in order to bond the new thin fill with he old surface. This applies only to the area under the pavement roper.

Transferring Grade from Stakes.—A handy level for transferring he grade from stakes to the center of the road is shown below.

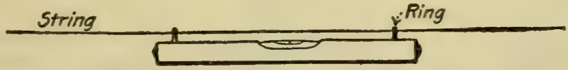


FIG. 336.—String level.

If well made and properly used it will transfer the grade elevation ₅o′ with an error of less than 2″, which is close enough for this stage of the construction: Its proper use depends on its being ocated midway between stake and hand. If held close to the nand the grade transfer will always be low due to sag of the string.

Ditches.—The ditches must always be dug out enough to protect he center grading before the fine grading (stone trench) is com-leted, and it is usually cheaper for the contractor, as well as better or the road, to dig them out before the fine grading begins.

Regulation of Materials in Fills.—In fills, particularly shallow ›nes, the road can be greatly improved by a judicious selection of ıvailable materials. Material taken from two nearby cuts, or ıt different depths in the same cut, will often vary in character ınd the most experienced man on the job should indicate which materials to use in the center of the fill, under the metalling, and

which on the sides. The soils in the order of value for fills are gravel, coarse sand, loam, and clay. For shallow fills on a good foundation, clay should not be used under the stone, and a good material must be overhauled or borrowed. It is better to avoid overhaul if possible, as it is an item liable to be disputed as to the amount. Where it is necessary, a good practical method of determining the amount of the small quantities of earth usually needed is to keep track of the number of wagonloads overhauled from station to station.

Sod may be used in the sides of the fill but should be kept at least 3′ outside of the pavement edge. It should never be used as a shoulder close to the stone or in the center of the fill under the metalling.

The author wishes to emphasize the importance of this regulation of material. At present the inspection of rough grading is often confined to keeping the sod from the center fill, and the center fill is made of dirt just as it happens along. As a result, the subgrade will vary greatly in character and if a uniform depth of stone is used over this "spotty" fill, the results are often not satisfactory, while if the depth of stone is varied to meet the subgrade conditions, an unnecessary amount of stone is used. In cases where there is no choice of earth materials, the stone depth must be made thick enough to meet the requirements of the grade. See Table 153, page 959 for macadam depths on different soils.

FINE GRADING FOR STONE TRENCH (MACADAM ROADS)

The fine grading includes the shaping and consolidation of the stone trench.

The construction shoulder must be at least 2.5′ wide and well consolidated in order to hold the macadam solidly during rolling. This must be watched continually by the inspector, as it is a point often slighted.

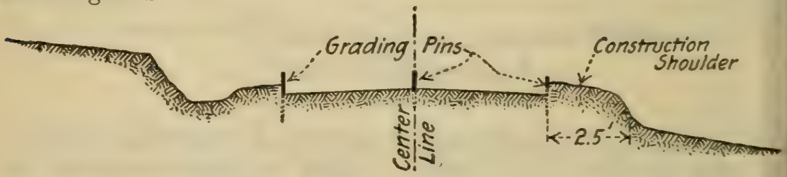


FIG. 337.

Shaping the Grade.—A simple guide for shaping the grade is shown in the accompanying sketch (Fig. 337) and consists of three strings (center and sides) stretched between pins driven at least every 50′ and preferably every 25′. The pins should not be placed at intervals of more than 50′, as this will cause objectionable sag in the lines and the grade will be undulating. On vertical curves at summits, the pins should be placed at from 12 to 25′ intervals. The grade elevation is transferred and the lines carefully set at their proper elevation by means of a straight-edge, level and rod, or by stretching a line between grade stakes on opposite sides of the road as previously described. The string level recommended for rough grading cannot be used, as it is not sufficiently accurate.

The general level of the finished consolidated fine grade should be correct to within 1″. This leeway of 1″ from the figured grade makes it possible to get satisfactory results without wasting time on finical work and does not appreciably affect the total amount of excavation, as the errors tend to balance. There should, however, be no short, small irregularities of grade noticeable to the eye. Continuous inspection on shaping the grade is not necessary.

Consolidating the Grade.—Most soils when slightly moist will consolidate readily if thoroughly rolled. Clay, heavy loams or excessively fine sandy loams (quicksand) will not pack when wet. Continued rolling is injurious for these soils in this condition, as they will "work" under the roller. If they occur only in small pockets, they can be removed and replaced with good material; if in stretches of any length the grade must dry out before placing the stone. Underdrains are constructed at this time, where necessary, and the surface ditches are cleaned out and made effective. Where a hard shower has softened the surface only of a previously consolidated grade of this kind and the contractor wishes to lay stone, the surface can be hardened by spreading a thin layer of gravel or waste ¾″ stone and rolling into the earth. This will help in preventing the stone teams from cutting up the grade.

Gravels and finely pulverized clay, or clay loams (deep dust), will not consolidate when dry; such material must be thoroughly sprinkled to get a compact grade. It is not, however, customary to sprinkle coarse gravels, even if slightly loose, as no objectionable results follow from placing stone on such a grade; deep clay or loam dust is objectionable and must be sprinkled.

Coarse sand makes an ideal foundation but is hard to keep in shape while placing the first layer of stone. In some cases sprinkling will harden it sufficiently; in others a layer of fine loam has been spread over the sand and flushed in with satisfactory results. Sometimes where loam is not available, a cheap cheesecloth has been spread over the top of shifting sand to prevent the stone from punching in too much under the roller. The author has never encountered any coarse sand that could not be satisfactorily treated by sprinkling and covering with 1 or 2″ of ¾″ stone; the blanket of ¾″ stone prevents the sand from squeezing up into the loose bottom stone and spreading the fragments.

While coarse sand makes a good foundation, a fine sand or sandy loam approaching quicksand is very treacherous; it is difficult to judge the degree of fineness at which a sand becomes treacherous, particularly when it is dry. A sieve test can be made (not over 30% should pass a 100 sieve), but a good practical method in the field is to saturate the material thoroughly with water; a satisfactory sand becomes more compact while an exceedingly fine sand gets "quaky."

SUBBASE MACADAM ROADS

Determination of Stone Depths and Construction of Subbase. Practically the only engineering problem that the constructing engineer has to solve is that of foundations. It is recognized by most designers and estimators that it is impossible from even a

careful preliminary examination of the soil to specify exactly the amounts and depths of foundation stone. To meet this an extra quantity of subbase or bottom stone is allowed the constructor, to be used as he sees fit. During the progress of the rough and fine grading the exact limits of the different kinds of subgrade soil are determined and the stone depths varied according to his judgment (see p. 437). Men that really understand this part of the work are hard to get, as it is only from extended experience and intelligent study of their own failures and successes that a sound judgment is developed. An examination of Table 153 (p. 959), will help a beginner. A good constructing engineer is much more difficult to find at present than a good technical designer.

Where subbase is used, the subgrade is dug out to the required extra depth and rolled if it is in such shape that it will not "work." Peat, muck, wet fine sand or wet clay cannot be rolled until the subbase is placed and filled. Where it is possible, such soils should be drained and allowed to dry before placing the base, but it is often not feasible to dry them enough to allow rolling, even though underdrainage is put in, which partially hardens them and successfully protects the road after the stone has been placed. This is particularly true on flats where it is hard to get an outlet for a drain or in the fine sands on which an underdrain has little effect on account of the capillary action of the material. Where a soft subgrade of this kind is encountered, a stony gravel makes the best subbase, as it contains no voids between the larger fragments and when rolled the soft underlying material cannot squeeze up through the course. In case boulder or quarry-stone base is used on a soft grade, it is necessary to lay them in close contact by hand and then fill the voids completely with gravel or stone before rolling; otherwise the subgrade material would squeeze up between the stones, separating them and partially destroying the efficiency of the base.

In the spring and fall of the year it is common to find good material so saturated from long-continued rains that it acts badly under the roller, and instead of waiting for the grade to dry out when the normal thickness of stone would be sufficient, subbase is often put in either to help the contractor so that he will not be delayed or because the engineer is misled as to the character of the material. This results in a waste of money. On the other hand clay, when thoroughly dry, is hard and firm, which often influences a new man to omit subbase where it will surely be needed.

The use of subbase should not depend too much on the action of the grade under the roller unless the degree of saturation of the material is considered, although it serves as a guide in locating doubtful spots. The final determination should depend on test pits or bar and core soundings, which develop the character of the underlying material. See Table 153, page 959, for macadam depths on different soils.

The subbase is constructed, as explained under Foundations, page 430, either of gravel, boulder or quarry stone. The depth is gaged by lines. The ratio of loose to rolled depth is given on page 1132.

Continuous inspection is not needed on subbase; the depth of grading is checked before the stone is placed and the width, depth, and workmanship can be readily determined after the base is completed, and by an occasional inspection during the progress of the work.

Bottom Stone.—The earth subgrade must be firm and compact before the stone is spread. Bottom stone must never be laid on a soft grade. One of the most common slips of inspection is to allow this to be done, and the result is a "punky" bottom course that is never up to standard. The distributing power of this course depends largely on the stone fragments being firmly interlocked; if the stone is placed on a soft grade and rolled, the earth will squeeze up between the fragments and separate them.

The depth of the loose stone is gaged by the lines or cubical wooden blocks placed on the subgrade. Blocks are more convenient than lines except over subbase of stone fills, where lines must be used to get a spread true to shape and grade. The ratio of loose to rolled depths is given on page 1168. It is impossible properly to consolidate more than $6\frac{1}{2}''$ of loose stone. If the depth of bottom course is greater than $5''$ consolidated thickness, it must be laid, compacted, and filled in two or more layers.

The loose stone is rolled until the stones are solidly interlocked and there is no movement under the roller. *A single* 10 *ton,* 3 *wheel roller can properly consolidate and fill about* 100 *to* 125 *consolidated cu. yd. per day of* 10 *hours.* A thin layer of satisfactory filler (see Materials, p. 715) is spread over the top, rolled, and broomed in; the process is repeated until the stone is thoroughly filled. Continuous inspection on bottom course is not necessary. The widths and depths can be readily checked by occasional inspection. The three points to be carefully watched during construction are: (1) that the grade is firm, (2) that the loose fragments are thoroughly rolled before the filler is applied, and (3) that the finished surface is true to shape and grade, as a permanently smooth top course cannot be constructed over a humpy bottom; the top course must be uniform in thickness. A great many inspectors believe the contractor when he tells them that he can smooth up the job with the top course. He can temporarily, but the second-season result is hell.

It is desirable to complete the bottom course well in advance of the top, in which case the contractor can work to advantage after rains, and the course will be better compacted by subjecting it to some traffic action.

Where local stone is crushed on the job and the stone used ranges in size from $1''$ to tailings, care must be used in spreading that the sizes are well mixed, as pockets of fine or coarse stone are objectionable. The simplest method of mixing is to run the different sizes into one bin at the crusher; if they are separated they can be well mixed by loading one end of the wagons with the $1\frac{1}{4}$ to $2\frac{1}{2}''$ and the other end with $2\frac{1}{2}$ to $3\frac{1}{2}''$, and when dumped on the grade they will run together. When difficulty is experienced with these methods in obtaining a well-mixed stone spread, the loose stone can be harrowed. Many specifications call for harrowing thor-

oughly where a large range of crushed-stone size are allowed in one course. If possible, tailings should be used as subbase. When used in the bottom course having a rolled depth of 4 or 5″, they should be placed in the lower part of the course, but for a 3″ depth they should be placed on top and broken with a knapping hammer into fragments of less than 3½″.

The filler should not be dumped directly on the stone unless absolutely necessary. Drawing the loads onto the unfilled stone loosens the course, and, also, at each pile of filler there is apt to be left an excess which is hard to clean off.

The approximate amount of filler required per 100′, and the spacing of 1½-yd. loads are given below. The amount varies for the different materials used.

Table 226.—Giving the Approximate Amount of Filler Required per 100′ of Road for Crushed Stone Macadam Bottom Courses of Different Widths and Depths, Using 0.35 Cu. Yd. of Filler per Cubic Yard of Rolled Bottom
(In cubic yards)

Width of macadam, feet	Rolled depth of bottom course, inches			
	3	4	5	6
10	3.2	4.3	5.4	6.6
12	3.8	5.1	6.5	7.6
14	4.5	6.0	7.5	9.0
15	4.9	6.4	8.0	9.9
16	5.2	6.9	8.6	10.4
18	5.9	7.9	9.7	11.8
20	6.4	8.6	10.8	12.8
22	7.0	9.4	11.8	14.2

Table 227.—Giving the Approximate Spacing of 1.5-Cu. Yd. Loads of Filler for the Widths and Depths Shown in the Preceding Table
(In feet)

Width of macadam, feet	Rolled depth of bottom course, inches			
	3	4	5	6
10	46	34	27	23
12	40	30	23	20
14	33	25	20	17
15	31	23	19	15
16	29	22	17	13
18	25	19	16	12
20	23	18	13	11
22	21	16	12	10

Grading and foundations have been treated at some length, as hey are the most difficult parts of the construction.

Pit-gravel Bottom or Subbase Bottom.—A stony gravel con-aining not over 15% of loam makes a satisfactory course; the epths vary from 4 to 18″; pit or creek gravel even when unusually oarse has from 40 to 60% of fine material; a suitable gravel for it-run bottom should not contain more fine material passing a ¼″ screen than coarse material retained on a ¼″ screen. If here is a large excess of fine, the gravel should be screened and emixed at the bin in proper proportions.

The great difficulty in this construction is to get proper con-olidation without too much delay. It is advisable to lay a course f this kind at least 2 weeks ahead of the top stone in order to give raffic and rains a chance to help consolidate the course. The ddition of 10% of loam to clean gravel will quicken the consolida-ion. This can be done either at the pit by leaving a thin layer of oam, when stripping, which runs down with the gravel in loading or y placing from ½ to 1″ of loam on top of the gravel as spread on he road. The author has succeeded in getting rapid consolidation y snatching loaded teams over the loose course with the road oller; the roller continually smooths out the gravel and eases the aul for the teams; the horses' hoofs and wagon wheels punch into he gravel and pack it down rapidly. Sprinkling helps. A gravel ottom consolidates unevenly and it is always necessary to reshape somewhat after consolidation; about 10 cts. per cubic yard should e allowed for this reshaping of crown and elimination of humps nd hollows. A properly consolidated gravel bottom will permit 4-ton load on 3½″ tires passing over it without making a wheel ark over ⅛″ deep; this is a simple available construction test. Ve have gone into some detail covering this construction as it is the ost economical type of bottom in a large number of cases but is ot generally favored because it is harder to consolidate than the ther types of bottom. With a 3″ or preferably a 4″ macadam top has proved perfectly satisfactory on Class III and IV traffic oads.

The depth of gravel is gaged by blocks or lines and the ratio loose to rolled depth is approximately 1.20.

Water-bound Top.—Water-bound top is constructed in the me way as the bottom course except that stone dust is used for a ler and the course is puddled as has been described (see Specifi-tions, p. 1454).

If the stone used is a local stone crushed on the job, the output the crusher must be carefully controlled, especially when selected oulders are used, as it is very important that the size and quality such stone shall be uniform.

aterials Required.

For amount of limestone screenings, see page 1168.
For amount of stone required, see page 1168.
For ratio of loose to rolled depths, see page 1168.
For suitability of materials, see page 440.
For amount of water, see page 1172.

Imported stone can be inspected on the cars. Aside from this, comparatively little inspection is required except at the stage when the loose stone has been rolled and before the screenings are spread. At this time the inspector should examine the rolled course very carefully to see that it is true to shape and has no short depressions or humps. The smooth-riding quality of the road depends on this inspection and too much care cannot be taken. This point is particularly emphasized, as many stone roads have been criticized as rough for automobile traffic. Any depressions are filled with stone of the same size as the body of the course and rolled, after which the course is again inspected and corrected until it is made true. The screenings are then spread, broomed in dry, and puddled. In puddling use plenty of water and roll rapidly. If a pipe line and hose are used, a pressure of 100 to 125 lb. at delivery should be maintained. The road can be conveniently puddled in stretches of 100 to 200′.

After the road has dried out and been open to traffic, if raveling occurs, it can usually be remedied by light sprinkling and rolling

Where the top course is granite, gneiss, or trap, it is often necessary to use a certain percentage of limestone dust with the norma screenings. The limestone is more effective when spread last filling the top voids of the course.

Bituminous Macadam: Penetration Method.

Amounts of material, see pages 446 *and* 1141.

The main points to be controlled in bituminous-macadam top are

1. Proper size of stone.
2. Uniformity of spread.
3. Proper depth of spread.
4. Proper preliminary rolling and truing up of stone spread.
5. Proper heating and spread of bitumen.
6. Insistence on thorough final rolling.
7. Construction inspection records.
8. See also Specifications (p. 1458).

Under careful inspection, a top course of this type is smoot riding and should not develop inequalities of surface over ⅜″ in 10

Practically all the inspection items have been discussed, but fo convenience of readers who merely refer to this paragraph withou following through the discussion in Chap. VI the essentials wi be repeated.

A uniform-sized clean grade of coarse stone is important; 1½ to 2½″ is usually specified and the inspector must examine a rail shipments during unloading and as delivered on the road to se that not over 15% of the stone as spread is less than 1¼″ in size Undersized or non-uniform stone should be rejected. In spreac ing the stone, small pockets of fine stone which always occur a intervals even with the best grade of aggregate must be dug ou and replaced with well-graded aggregate. The depth of the loos spread must be checked. The depth of spread is usually regulate by cubical blocks of wood resting on the subgrade. The amour of stone used can be checked by railroad weights if imported ston

is used. For the proper amount of coarse aggregate, see page 447. After the preliminary rolling, a careful inspection of the course should be made for humps or hollows. This is the proper time to eliminate such defects, and all inequalities in the surface must be corrected by removing a small amount of the stone or adding additional 1¼ to 2½″ size and rerolling. Inequalities never can be fixed by the addition of small-sized stone. Stone spread does not require continuous inspection, as all faults can be detected by examination at any time before the bitumen is applied.

A careful check must be kept on the temperature of the bitumen, as overheating is very injurious and underheating spoils a free-flowing spread. Temperature should be tested with a thermometer at short intervals, but after a little practice the inspector can tell by visual inspection whether the temperature is proper. If too hot, a heavy white smoke develops on pouring. If too cold, the bitumen pour is a rubbery-like sheet. Maximum and minimum temperatures are given in all specifications and vary for the material used. The inspector must reject all overheated material as too many failures have resulted from carelessness in overheating.

In applying by whatever method, care must be exercised to prevent frequent cases of overlap, as waves or humps develop at these points. These defects do not appear for some time after the road is opened for traffic and the inexperienced inspector fails to realize the necessity for care in this particular. As soon as the bitumen is spread, the inspector must examine the spread carefully, and where pools of bitumen occur (a few cases will always occur even with the greatest care), the entire top course (stone and all) must be removed and replaced with new stone, tamped or rolled, and repoured. Lean spots should be given a little extra bitumen. The inspection of bituminous application must be continuous and is vitally important in the success of the pavement. Specifications generally state that the stone must be clean and dry. Bitumen should not be spread if the stone is dirty, but practically a slight dampness is not injurious. It should not be wet but a slight dampness does no harm; a practical test is that there must be no pools of water in the bottom of the course and the stones must not be so damp that a hissing sound is produced when the bitumen is applied at a temperature of 300 to 340°F. In the writer's opinion, the air temperature should not be less than 50°F., as bitumen applied in cold weather is so chilled when it strikes the stone that an excessive amount is retained on the surface. As soon as the bitumen is applied, a thin layer of ¾″ stone is spread over the surface and rolled lightly; continued rolling at this point is injurious, as freshly laid bituminous tops tend to shove under the roller and form waves. The road can be thoroughly rolled and shaped to advantage only after the bitumen has had some time to harden. Good results have been obtained by rolling thoroughly the succeeding day after the binder is applied unless in the meantime rain has saturated the course, in which case it must be allowed to dry before rolling. In the author's opinion, the best method of rolling is to roll twice over lightly each morning for 10 days and gradually bring the road down to a hard firm surface

giving it a very thorough final rolling at the end of a week or 10 da: The roller must not be reversed suddenly. It must run easi to rest and start gradually. Before rolling is started the $\frac{3}{}$ stone should be spread evenly and any excess broomed off.

One roller can handle an average of approx. 80–100 cu. yd. consc dated top per day. If the rate of spread exceeds this amou additional rollers will be required. Rollers should be the 3 wh type of at least 10 tons weight.

The amount of bitumen spread per square yard is usua controlled by spreading a given number of pots or hods or tai in a given length of the road. These units of length can read be marked off by the inspector with a stick or tape. This meth will be satisfactory if checked up twice a day by the number barrels used. When the binder is heated in small kettles, it v sometimes catch fire, but this is usually due to scale which l collected in the tank, and if cleaned out, it generally remedies trouble. Bitumen has different volumes at different temperatu (see following table). The inspector should bear this in mind; rate of application generally applies to 60°F., so that a correct is necessary if tanks are rated by volume capacity at spread temperatures of 250 to 350°F. The simplest method of measu ment and payment is by the pound or ton weight unit bases. volume-correction table follows.

TABLE 228

To 400°F. is approximately	12 %	volume increase
To 350°F. is approximately	10 %	volume increase
To 300°F. is approximately	8 %	volume increase
To 250°F. is approximately	6 %	volume increase
To 200°F. is approximately	4 %	volume increase
To 150°F. is approximately	2 %	volume increase
To 60°F. is approximately	0 %	volume increase

Where bituminous materials are heated by steam it is of convenient to know the temperature of steam at different p sures; the following table is inserted for this purpose.

TABLE 229

Pressure gage, pounds per square inch	Temperature of steam, degrees Fahrenheit	Pressure gage, pounds per square inch	Temperature of steam, degrees Fahrenheit	Pressure gage, pounds per square inch	Temper ture o steam degree Fahrenh
15[1]	213	100	328	200	382
20	228	120	341	220	390
40	267	140	353	240	397
60	293	160	363	260	404
80	312	180	373	280	411
100	328	200	382	300	417

[1] Normal air pressure, 15 lb.; to get ordinary steam gage reading subt 15 lb. from the values given in this table.

INSPECTION RECORD FORM

Name of Road: Pittsford-Naples

Date: July 21, 1922

ıspector: John Doe

ngineer: Richard Roe

ontractor: John Smith

Record of Inspection

ottom course: Examined and approved Sta. 125 + 50 to 140 + 00. Two depressions Sta. 135 + 20 and 137 + 30 filled in with No. 3 stone rolled and filled.

op course, stone spread: Sta. 125 + 50 to 131 + 25 examined and approved; no corrections necessary for depth or uniformity.

nder coat (asphalt): Sta. 119 to 124 + 10.

Official acceptance, dated July 1, 1922.
Method, hand spread.
No. sq. yd. covered, 910.
No. gal. used, 1,650 ±.
Rate of application, 1.8 gal. per sq. yd.
Temperature, Max. 340°, Min. 290°
Air temperature, 60° to 80°.

al coat: None used on this road.

nish rolling: Sta. 85 to 90.
Routine rolling 90 to 126.

emarks: 40 gal. bitumen rejected on account of overheating small amount left in one kettle.

Signed,
JOHN DOE

CEMENT-CONCRETE PAVEMENTS

Amounts of material, see pages 461 *and* 1145.

"**Manipulation of Concrete. Inspection Details.**—The following ıotation from New York Instructions (1923) outlines the main oints to be considered in connection with concrete pavement onstruction:

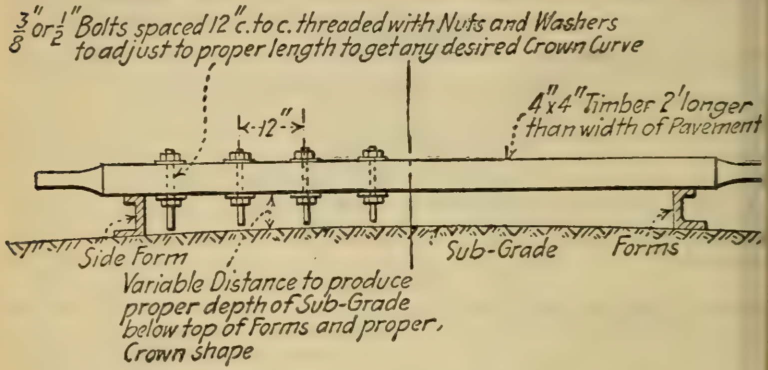
NE COURSE PLAIN AND REINFORCED CONCRETE

"The fundamental requirements to be followed in building a ain or reinforced-concrete pavement according to our Standard ecifications are:

1. Properly prepared subgrade.
2. Thorough and complete drainage system.
3. Full depth of pavement.
4. Full cement content.
5. Clean and well-graded aggregates.
6. Proper proportioning of aggregates.
7. Accurate water measurement.
8. Mixing interval to be at least 1 minute.
9. Placing reinforcing material as specified.
10. Proper compaction of concrete.
11. Staking joints securely and placing them exactly perpendicular.
12. Finishing at the proper time and according to specifications.
13. Curing for the full period called for in the specifications.

"The surface of this type of pavementcan be made even and tr and free from waves, irregularities, and uneven joints. Wh defects are found, they are the result of lax inspection and po workmanship.

"**Preliminary Preparation.**—Before starting to lay the concre pavement, the inspector must see that the contractor has l concrete mixer, subgrade tester, roller and belt or finishi machine, split float and bridge for finishing at joints, straight-ed template for reinforcement, edging tools, stone forks, chargi conveyances (of uniform size), measuring boxes, steel bulkhea forms, pins for staking, striking template, reinforcing fabric flat sheets, expansion-joint material in straight full or half lengt



Sub-grade tester.
FIG. 338.—Sub-grade tester.

covering canvases and forms for same. The mixer must equipped with timing and water-measuring devices, as well satisfactory charging skip and discharging chute or bucket specified. It is necessary that all this equipment, tools, material be first class and approved by the division engin before the work of placing concrete wearing surface may be star and that they be kept in first-class condition during the progr of the work.

"**Aggregate.**—The fine and coarse aggregate shall be well-grad clean products which have been tested and approved by engineer of tests before being used in the work.[1] Field te must be made daily for sizing, loam content, and orga impurities. The inspector must watch carefully the mater as they are delivered to the work and in case of rail shipments m have an understanding with the contractor that he must notified in order that the cars can be inspected for acceptance rejection before unloading.[2]

"Each material must be kept clean and not allowed to beco mixed with dirt and other materials. Fine aggregates must

[1] See Chapter II for test methods.
[2] Central batching from large stock is generally specified to prevent d aggregate.

ıoveled and coarse aggregates forked from the tops of the piles ı order to minimize the chances of picking up dirt. Aggregates ıat cannot be forked or shoveled clean must be rejected.

"Frequent visits should be paid to the sand pits and quarries, pecially those in which there are questionable materials. In one quarries, consideration must be given to stripping and the sposal of unsatisfactory waste. Screen openings must be ıecked and the proper facilities adopted that will insure a ıorough mixture of sizes.

"Cement must be carefully stored and kept dry. Under no ınditions shall it be placed on the ground. Samples of each car, hen not tested at the plant in accordance with instructions, ust be sent to the laboratory. Pending a report the cement ınnot be used.

"**Forms.**—Forms shall be erected only after the subgrade has ıen properly prepared. The subgrade tester shall be operated om these forms in accordance with the specifications to insure e proper depth for the pavement at all points. The subgrade ster must remain at the mixer at all times and must be used at ch move of the mixer. [*This stipulation is not always feasible. It better to check the grade with the tester for a hundred feet ahead of the ixer and then correct any small rutting due the teaming or moving e mixer by eye. A tester under the mixer boom is an abomina- on.*] It always must be used in a vertical position and when ıing moved shall not be raised from the side forms. A string vel should never be used in setting side form. A suitable true raight-edge and 3′ carpenter's level must be used and the level ust be checked for accuracy by reversing it.

"Only straight, substantial, and clean forms shall be used. Wood ırms should only be used for curves of less than 150′ radius. All ısatisfactory or rejected forms shall be removed from the work.

"Wooden forms must be used on curves of 150′ radius and less. ıwcuts shall be made at frequent intervals to obtain the necessary ue curvature.

"All forms must be oiled or greased each time before use. traightening must be done whenever necessary.

ABLE 230.—MIDDLE ORDINATES FOR STRING LINING CURVES, IN INCHES

Length of chord in feet along gage.....	100	98	93	87	82	76	69	62	58
Middle ordinate for 1° curve..........	2⅝	2½	2¼	2	1¾	1½	1¼	1	⅞

Length of chord in feet along gage........	53	49	44	38	35	30	25	20	15
Middle ordinate for 1° curve............	¾	⅝	½	⅜	5/16	¼	3/16	⅛	1/16

To get middle ordinate for any curve multiply the value given by the egree of curvature of the curve in question.

"Forms must be set accurately and substantially. Poor and grade are not only annoying in appearance but result in une surfaces and indicate careless work. Forms shall be prote against any disturbances such as dumping materials.

"The subgrade must be brought to a true elevation and ro to a width of at least 18″ outside of the form line. The prac of blocking up forms on stones where the subgrade is low and af wards tamping a loose dirt fill inside and along the form must n be allowed. If the subgrade is found to be too low after forms placed, they must be removed, the subgrade brought to the pr elevation and rolled for the required width before the forms finally reset to a full and even bearing on the subgrade.

"Two hundred feet on both sides must be set at all time advance of the mixer. There shall be string line stretches on side, then checked by eye in order to detect any irregulari Special attention should be given to joints in forms, and when of forms do not coincide at these points, the forms should rejected. Short curves and parts of the tangents should be out at the same time in order to get an intelligent check. Mi ordinates for various lengths of chords for the different cu should be at command, in order to eliminate kinks and une curves.[1] A line of forms shall be securely staked to this string and then the opposite side is placed. Care must be used to get proper width and elevation for opposite forms.

"Curves shall be widened and superelevated in accordance standards when indicated on the plans.

"Grades as shown on plan shall be on the normal center lin the roadway on superelevated curves. No concreting shall s on a widened curve until forms are erected and checked on b sides.

"All forms must be removed within 24 hr. after concreting.

"The inspector should carefully examine the edges of the pa ment immediately after the removal of the side forms and concrete is honeycombed, have it sealed with cement-sand mor afterward insisting on a more adequate spading of the conc adjacent to side forms.

"**Measuring Devices, Checking Quantities and Compositio** Proportions shall not be varied for any reason without appr of the division engineer. The correct measuring of all materia essential in securing satisfactory work.

"The contents of all proportioning boxes and batch boxes m be determined by accurate measurements and such change are necessary in regulating the proportioning must be made p to beginning operations.

"The inspector must keep accurate check on the amount of cem used and maintain a daily record of the length of pavement and the quantities of cement required and used.

"The inspector shall arrange for the weighing of an occasio bag of cement to see that they contain 94 lb. net (with an allo variation of 5%) and must be sure that the man dumping cem shakes the bag well in order to get the entire amount out of sack.

[1] See page 1301.

"The number of empty bags must be counted about every 2 hr. nd then placed in separate piles or removed from the work. his method will relieve accumulation of any shortage or excess.

"The use of industrial systems will require one inspector at the aterial yards. Cars on which the aggregates are measured irect must have separate and vertical compartments for each ind of aggregate and must be of the exact size of the batch in rder to insure correct proportions.

"Combined aggregates shall not be permitted to be measured in ertical containers of one opening. In this case especially arranged easuring devices must be used for each aggregate from which he container can be filled.

"Care must be used in protecting the cement against wind during he loading process. If necessary, erect a canopy. In cars when he cement will be exposed, lids or covers must be used at all times. Inder no conditions permit cement that cannot be used immeditely to be loaded on industrial cars.

"Some jobs will require different methods from these, depending n the contractor's equipment. Consideration must be given and there are any unusual features, the division engineer should be alled to the work for final decisions as to the method to be used y the inspector.

"**Consistency.**—The consistency of concrete is very important ecause the strength is greatly reduced by the use of excess water. Only sufficient water shall be used that will form a concrete similar 1 consistency to moist (not wet) earth when a finishing machine is sed and quaking wet for hand finishing.[1] The inspector must ote the moisture of the sand in order to vary, whenever necessary, he amount of water. (See also pp. 461 and 744 for consistency nd slump tests.)

"The contractor shall be required to have a glass gage on the nixer in order visually to determine the quantity of water for each atch. Examination must be made of all valves and pipes in the nixer to detect leaks which cause non-uniform amounts of water er batch.

"The concrete shall be particularly dry for finishing-machine work. A wet concrete will not only be low in strength but a scale of nortar may be formed which will peel off in course of time under raffic. Frequent examinations throughout the day's work should e made in the recently finished concrete by inserting vertically a lunt end of a pencil in the surface in order to detect excess morar. There should be only sufficient mortar completely to cover he coarse aggregate.

"Non-uniformity in the consistency of the concrete results in neven surfaces; therefore, the inspector must correct at once aults in the water-supply system of the mixer and not allow the vork to proceed until these faults have been found and corrected.

"After the pavement is finished and before it hardens, be sure hat no stones project above the surface or that the surface appears

[1] Avoid extremely dry concrete, as under the usual inspection better esults are obtained with a fairly easy-flowing consistency.

honeycombed. Have these faults corrected by using a hand floa
the reapplication of the finishing machine.

"**Mixing.**[1]—The concrete mixer must be equipped with appro
timing and water-measuring devices and an approved device
discharging the concrete, all of which must be kept in work

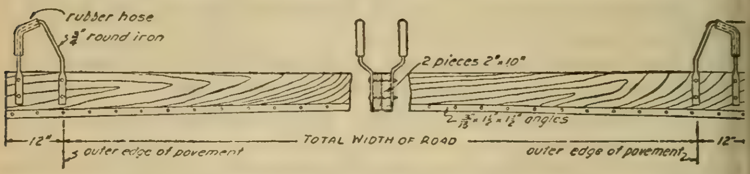


FIG. 339.—Screed strike board.

condition at all times. The time, as noted in the specificat
must be strictly adhered to. The concrete must not be dischar
until the full time has expired. At frequent intervals the inspe
should check the time of mixing. The time of mixing shal
measured from the time the last material enters the drum from
loading skip until the first material is discharged into the buc

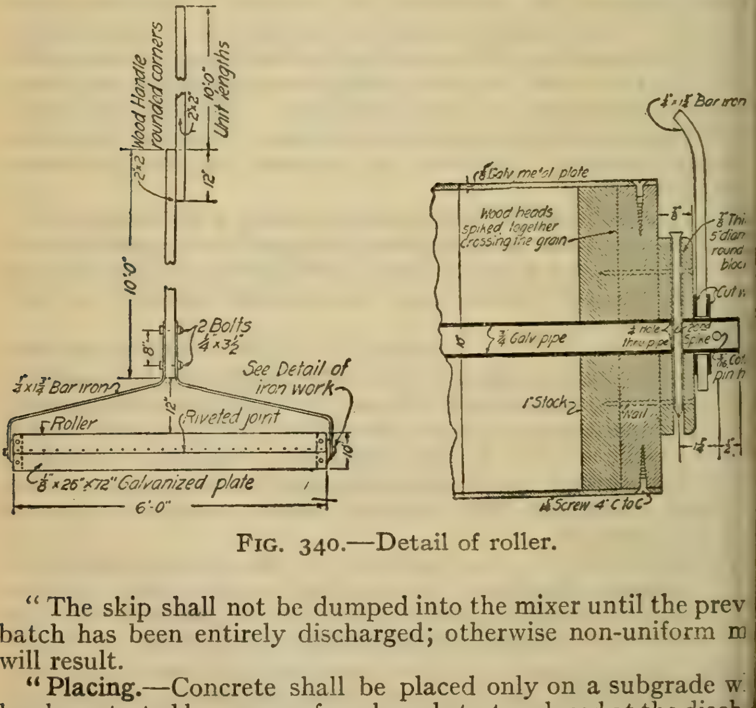


FIG. 340.—Detail of roller.

"The skip shall not be dumped into the mixer until the prev
batch has been entirely discharged; otherwise non-uniform m
will result.

"**Placing.**—Concrete shall be placed only on a subgrade w
has been tested by means of a subgrade tester placed at the disch
end of the mixer. The subgrade must be firm and smooth an

[1] For effect of time of mixing on strength, see Chapter VI, page 475.

material removed. Loose material along the forms must be ›ved by means of a square-point shovel or spade.

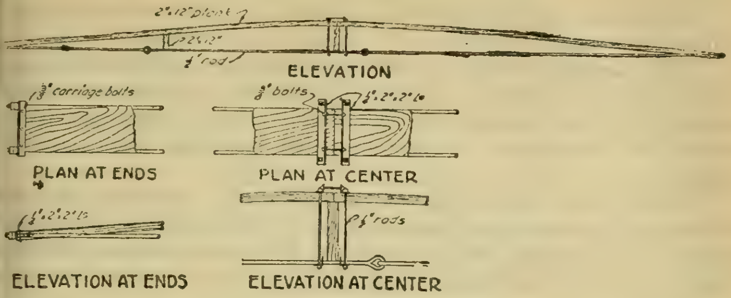


FIG. 341.—Finishing bridge.

The first layer of concrete shall be deposited to the depth of ic reinforcing, 2″ below the surface of the pavement and struck

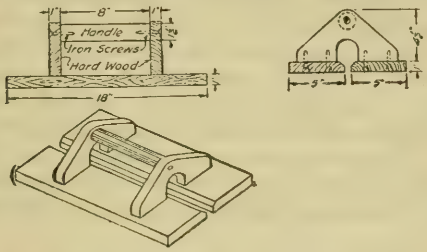


FIG. 342.—Split float.

vith an approved template. Rod reinforcement shall be placed rom all transverse expansion and construction joints and at a th equal to 2″.

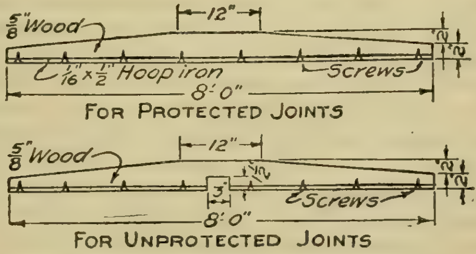


FIG. 343.—Testing straight edge.

The fabric reinforcement must be perfectly flat when placed in work. If furnished in rolls, it must be flattened by the use of achine. The fabric must extend to within 2″ of all sides and st be lapped as specified. It must be protected before use from

the weather except as required from day to day. Under no co dition shall it be stored in the open, especially during the win months.

"The fabric reinforcement is placed 2″ below the surface. striking template insuring a 2″ depth must be used.

"After the placement of fabric reinforcement, the remaining of concrete is placed. It must be placed of sufficient depth have a slight excess ahead of the strike board for finishing. Do r permit the workmen to walk on this concrete after the init spreading.

"Evenness of finished pavement surface is insured by the proj even spreading and distribution from the drop bucket of the mix Uneven distribution and attempts to fill in low places with mor results in a wavy surface which is detected only after the mor has hardened.

"**Finishing.**—As soon as the full depth of concrete has be spread, it shall be struck off, either by a hand template or approv finishing machine. A slight excess of concrete must be maintair ahead of the strikeboard. Depressions and holes must be fil with concrete, not mortar, and must be retamped.

"A hand template must be of specified length and weight. shall be first worked in a crosswise movement and then followed tamping, to insure a proper cross-section and the imbedding coarse aggregate. The template shall be operated until within of an expansion joint, and then lifted to the joint and worked ba from the joint. Excess mortar and concrete must be carefu removed and in no case be permitted to remain. Templa (both hand and finishing machine) must be checked frequen for crown.

"Immediately after tamping, the sides must be spaded conti ously in order to prevent honeycombed sections and to insure sa factory edging. Any excess mortar or concrete must be remov The sides along the bulkhead and filler must be spaded to ins dense surfaces and to ease the lifting of the bulkhead agai raising the filler.

"Hand tamping shall be followed by a roller of standard dim sions and weight. The use of roller must not be delayed until surface is partially set; otherwise the concrete will be lifted. T early rolling will remove too much mortar and not water. T roller must be moved slowly, not to exceed 16′ in 40 sec., and m be passed over and back, the roller then being lifted and advan one-half its length, the rolling operation then being repeat The first rolling must proceed from the end of the slab first laid, a free water must be allowed to come to the surface between ea rolling. The roller must be wetted after each operation and ke clean and true in form.

"Belting of the surface shall follow. The belt shall be kept mo or oiled and cleaned at all times, in order that the full width c rest on the pavement. The belt must not be so heavy as to ma the finished surface. The belt shall be operated in a crossw movement, so that any part for the total and breadth rests the pavement.

There should be two beltings. The first must be slow to take irregularities, remove excess water and smooth out the surface. second shall be a little faster in the forward motion to give the n and prevent markings. Never permit a belt to remain on concrete.

Approved finishing machines may be used in place of hand work. n such is the case, it is necessary for the contractor to have pment for hand work which can be resorted to in the case of a kdown in the finishing machine.

In the use of a finishing machine there is a tendency of the ator to perform too many operations with the result that ss mortar accumulates. The operator should be so instructed trained as to finish the pavement with one or two strikings, or two tampings, and two beltings. The parts of the machine ll operations must at all times be regulated to insure contact the surface at all points. The belt must be kept moist.

On grades exceeding 3%, the surface of the pavement must be d with a hand roller following the passage of the finishing ine in the manner prescribed for finishing by hand.

One of the most frequent defects in finishing-machine work is of irregular wavy surface. This is frequently caused by the ine moving too fast, the use of the machine for spreading by ing an excess of material in front of the blade, failure to feed erly sufficient material by hand to the tamper and most often unning the tamper while the machine is not moving. The ing machine should move forward at a uniform rate of speed. blade should not be used for moving any considerable amount aterial, only sufficient material being kept in front of the blade oduce a full section. After the finishing machine has come to p, before the tamping is resumed, the machine should be d back a few feet and then started forward, and the tamping esumed until the machine has moved forward for at least 1′.

"Edging shall not be done too early after the belting.

"Curves shall be widened and superelevated where necessary. ransitions, intermediate pins must be set exactly at grade at nnings and endings, together with one or two between sections.

"The finished crown should be checked frequently by using a ; and small blocks the height of the crown, the blocks being d on the side forms and a string stretched from top to top of s. To insure a proper crown it is frequently necessary to the template shaped to an arc ¼″ greater than the required to offset the slump of the concrete during hardening.

"**Joints.**—All expansion and construction transverse and longitu- joints must be vertical, level, and free from irregularity. ularities caused by improper and careless work produce defects pavement such as one slab rising higher than the other and onal cracks.

"Before using joint filler, it must be checked for all dimensions uality. Many poor results are obtained by joints that are ort and of insufficient depth. Shearing of the edges and sides ncrete under expansion ruptures the concrete and causes ng.

"Joint filler must be furnished in flat sections. No branc filler shall be used unless approved by the engineer of tests.

"Only when indicated in the specifications may minimum len be connected as one continuous length. These short lengths n be joined by lacing, staples or other suitable means before b installed.

"The steel bulkhead shall be of exact dimensions and oile greased at all times. The workman shall be required to lay i a flat area when not in use, in order to keep it perfectly strai Any kinks must be straightened immediately after being noti It shall be firmly staked on the side towards the mixer with pins, the number and length depending on the subgrade condit and methods of finishing. The joint filler shall be set on the of the bulkhead away from the mixer.

"A steel bulkhead against which the expansion joint fill placed must be firmly supported by at least 10 iron pins, 12 to in length depending on the subgrade; 5 pins along both sides o bulkhead and filler with 2″ below the surface.

"These pins must be long enough and are to remain in pla order to insure straight joints in all directions. When filler is placed directly against hardened concrete, 5 pins sha used on the side away from the concrete.

"The joint filler shall be set just flush with the pavement.

"A small amount of spading shall be done along the oile greased bulkhead in order to ease removal. The bulkhead not be removed until at least 10′ of concrete has been placed a and the striking and tamping has been done on either sic immediately over it. No striking or tamping shall be perm after the bulkhead is removed, other than just enough tan with a rod to fill the cavity left by the bulkhead. The bulk shall be removed by raising opposite ends at the same time thr holes in either end, into which hooks are inserted.

"After the removal of the bulkhead on hand-finished work the filler is higher than the surface, a split float or straight in accordance with the standards shall be used, after whicl edging tool of 1/8″ radius is operated on either side.

"For finishing machine work, where the filler is slightly r or flush, the edges shall be rounded with the above radius All joint finishing shall be done by a skilled workman fr finishing bridge. On no work shall connected concrete be perm to remain over the filler, as this condition causes serious sp under traffic. Edging is to be done along construction joints the 1/8″ radius tool.

"The belt should be operated immediately on each of the joint so as to give a uniform appearance to the surface.

"The surface of pavement adjacent to joints must be finishec the utmost care by an experienced workman in order to ob uneven joints which induce an uneven, bumpy riding surface. 6′ straight-edge must be used in testing all surfaces adjace joints prior to the last belting of the surface, and when the su is uneven it must be corrected.

As soon as the forms are removed, investigation must be made to rmine if any fillers do not extend entirely through from one side e other. If not, the contractor shall open the connected sides eans of a chisel. Under no condition permit shoulder material e deposited along the sides until there is positive assurance the joints are open.

Protection.—The surface shall be protected with canvas as fied. The canvas shall never be dragged over the surface of green concrete. In warm weather when the temperature is e 70°F., the surface of the concrete shall be thoroughly wetted on after it is finished as it is possible to do so without injuring urface, the canvas carried over the concrete and lowered verti- onto the surface, and the canvas kept wet. A set of frames pport canvas covering shall be kept on hand at all times near concreting work to be used in the event of warm or rainy her, as the canvas must not be laid on fresh concrete. In cool her the canvas may be dispensed with. Hair checking or ing can sometimes be eliminated by spraying fresh concrete, a nozzle that will produce a fine spray or fog, but care must aken not to use a nozzle that will cause pits in the surface. is does not prevent hair checking and the materials are dry, should be thoroughly wet down before they are placed in the r. As soon as the surface has hardened sufficiently so that ll not be injured, the canvas shall be removed. It must be oughly wetted and covered with earth or other approved rial at least 2″ deep, which must be kept wet at least 8 days prinkling with water, except in cold, late fall weather. When is used in place of earth for covering, the straw should be d to a minimum depth of 4″ and kept wet for a period of at 8 days during warm weather. Straw shall remain in place period of at least 18 days under the most favorable conditions. ersons must be kept off the concrete surface for 3 days. All c must be kept off the surface for the full time specified and e late fall, the time of curing must be extended 1 week. After specified time has elapsed, the covering material shall be ved and the pavement swept clean. If found necessary, owing cal conditions, the contractor must furnish a watchman at mes to secure the required protection. In some instances it be necessary for the contractor to construct temporary foot es over the surface of the concrete to permit the necessary ge of pedestrians or cattle from one side of the road to the ."

ncreting during Rain Storms.—Inexperienced inspectors are times puzzled to make a reasonable interpretation in regard pping work on account of rain and they worry their heads off y see a cloud the size of a hand in the sky. From a practical point it is safe to instruct them not to worry; in case of rain en will quit before it rains hard enough to do any serious ge; as a matter of fact a light rain gives an excellent spray e finish much superior to any hand manipulation and I have had any concrete seriously damaged even by hard showers; men quit in the midst of a block and leave the work without

heading up it is necessary to reject and dig out a few feet o
pavement to get a good vertical connection.

Protection of Concrete in Warm Weather.—Hot sun and dı winds damage the surface-wearing power of concrete pavem and also often produce so-called temperature and wind ch which are unsightly to say the least. Concrete should be prote in hot weather in order to get the best results; the methods usı adopted are burlap or canvas covers on frames, pending, cover sprinkled or continuous spray sprinkling. Special pr tion of this kind is not necessary when the temperature in the sp or fall of the year gets below 50 or 60°F. Surface checks (hair cracks) are difficult to prevent under a hot sun and st dry wind, as they develop before the finishing is complete before it is possible to protect the concrete by canvas co Under these conditions a light spray applied continuously the surface is belted seems to help reduce these checks. If do form, a fairly satisfactory repair is to omit the earth cove the next day, and after the surface is fairly dry, fill the checks dry cement; this is done by sprinkling it along the checks pushing it in with a small broom.

Concreting in Cold Weather.—Cold-weather work in conne with concrete paving is a rare emergency and should be perm only to finish a short piece of incomplete work. With the ut care results are rarely good, as concrete in pavements cann as well protected as building concrete under unfavorable we conditions. Concrete should never be placed on a frozen subg

The simplest solution where an unexpected cold snap dev is to heat the aggregates and protect the concrete by covering canvas, straw, hay or earth. The addition of calcium ch (3½% by weight) to the mixing water will prevent dama the temperature does not fall below 28°. A simple meth using this chemical which has the property of reducing the fre point of water and hastening the set of concrete is describ follows in "Recommended Practice" of the Portland Ce Association: "It can best be added to the mix by making a centrated solution 1½ lb. per gal. of water; this concentrated tion is added to the mixing water at the rate of a gallon per sa cement used." This treatment adds about 15 cts. per cu. yd. cost of the concrete. Chemical means alone should not be on to prevent damage; heating and cover should also be used

Inspection and Engineering Records.—Inspectors shoul required to turn in daily signed records of the essentials in conne with the pavement work. These records are very useful in ca dispute or lawsuits.

The following forms have been used by the author. The be easily and quickly filled in. They are prepared in book fo pocket size. Two inspectors are usually required: a inspector who is responsible for the measurement and quality materials and an inspector at the mixer responsible for the g forms, and manipulation.

MATERIAL INSPECTOR'S REPORT

me of Road: ____________________

te: Sept. 21, 1922

pector's Signature: John Doe

terials Received on Job:

Cement

Car Nos.	Amount	Brand	Acceptance No.
L. & N. 21435	231 bbl.	Atlas	B. R. 2645

Sand

Car Nos.	Amount	Source	Test No.
L. V. 25462	110,500 lb.	Continental	B. R. 1750
Penna. 175133	104,700 lb.	Oaks	Field No. 7

Stone

Car Nos.	Amount	Source	Test No.
L. V. 10546	103,400 lb.	LeRoy	B. R. 1120

Materials Delivered to Mixer

nent	304.5 bbl.
d, approximately	115 tons
ne, approximately	170 tons

PAVEMENT INSPECTOR'S REPORT

me of Road: ____________________

te: Sept. 21, 1922

pector's Signature: Richard Roe

Approval of Grade and Forms

Sta. to Sta.	Time of Approval
25 + 30 − 28 + 20	7 a.m.
28 + 20 − 30 + 50	1 p.m.

Tests of Mixer (twice daily)

Time of Mix per Seconds, Batch	Number of Revolutions per Batch	Time Test Made
58	15	8 a.m.
59	15½	3 p.m.

Concrete Data (4 times daily)

Sta. to Sta.	Cu. Yd.	Cement	Cement Factor	Time
5 + 30 − 26 + 80	60.0	117.50	1.96	10 a.m.
5 + 30 − 27 + 35	82.0	158.25	1.93	1 p.m.
5 + 30 − 28 + 05	110.0	210.00	1.91	3 p.m.
5 + 30 − 29 + 23	157.2	302.00	1.92	6 p.m.

Remarks

vious day's run covered with earth and sprinkled.
vious day's run shows satisfactory edge.
nent tally by batchmaker disagrees with material inspector by 2.5 bbl.

SAMPLE ENGINEER'S DIARY

The diary of the engineer in charge shows all essentials of the work for poses of record and possible lawsuits.

Name of Road: ______________________________
Date: Sept. 21, 1922
Engineer: John Smith
Engineering Force:
 John Smith, General Supervision
 John Doe, Materials
 Richard Roe, Pavement Inspection
Headquarters Inspector visited work
Contractor's Work:
 Force: 70 men
  8 teams
  8 Ford trucks.
 Work: Steam Shovel Station 200 to 201
  Fine Grade Sta. 80 to 90
  Concrete Pavement Sta. 25 + 30 − 29 + 23
   Cement Factor 1.92
Materials Delivered:
 Cement L. & N. 21435.................................... 231
 Sand L. V. 25462.. 110,500
 Penn. 175133.. 104,700
 Stone L. V. 10546....................................... 103,400
Correspondence: See letter attached giving ruling on maximum ce factor.

Sept. 21,

Mr. John Brown
 Contractor
  City
Dear Sir:

The following letter (a copy of which has been sent to the division engi states definitely my attitude and ruling as Engineer in charge of Road — in regard to the amount of cement that I can properly certify for pay as used in the concrete pavement work. If you are dissatisfied with ruling, you can appeal to the division engineer. The following ruling apply for all estimates unless I receive definite written instructions fro division engineer to modify this ruling. This letter is sent to you a time in order to give you ample time to make any necessary changes in batching procedure so that there will be no loss to you on the cement on completion of the road. This formal action is necessary as your ce factor has been excessively high.

I will certify for payment all cement actually used in pavement wo to an amount which produces an average cement factor for the entir of not to exceed 2.02 bbl. per cubic yard of concrete pavement. not certify to any total final excess of cement used over and above this on the ground that it is due to careless batching of the sand and stone order to give you ample opportunity to avoid final loss, I will certif pavement as satisfactory where the daily cement factor does not fall 1.80 but will not accept any pavement concrete having a lower factor 1.80 as reported by my inspector four times daily. You are to con using three whole bags of cement per batch, and any variations in procedure are to be made in connection with the sand and stone.

This ruling is based on the following data:

The amount of cement provided in your contract is based on 1.9 per cu. yd. of concrete pavement 1 : 1½ : 3 mix. Based on previous struction experience with this mix I instructed you to use for a thre batch 4.50 cu. ft. of sand and 9.00 cu. ft. of stone. Under this basis o portioning properly and accurately batched it has been my experience the 1.90 factor could have been easily maintained and there would have no overrun of cement on the contract.

My original instructions to you in this matter of batching were offi overruled by the department on the ground that they did not ex comply with the Specifications and we were both instructed to batch bags of cement, 4.28 cu. ft. of sand, and 8.56 cu. ft. of stone. This raises the cement factor about 5% and under this ruling I am willin justified in certifying a maximum of 2.02 bbl. per cu. yd. where this an

tually used. This will involve a possible overrun on the contract of t 750 bbl. of cement (Item 17) and there is no question in my mind but this overrun should be approved under the batching instructions we received.

to date however you have used 2.10 bbl. per cu. yd. of pavement and amount is excessive and not warranted. It is apparently due to a age of stone and sand in the mix. Between Sta. 157–86 and 121–68 used 2,110,000 lb. of stone (railroad weights) and 2,246.50 bbl. of cement. he basis of batching three bags of cement, 4.28 cu. ft. of sand, and 8.56 t. of stone you should use at least 990 lb. of stone per bbl. of cement. quality of grade has no effect on this basis of figuring.) Between these ons you should have used at least 2,224,000 lb. of stone, showing a age of 114,000 lb. or 5% of the total. Stone amounts to be about 80% e compacted concrete and a shortage of 5% would raise the cement factor t 4%. The average cement factor between these stations was 2.09 or % above the amount I am willing to certify.

a similar manner between Sta. 157–86 and 128–15 you used 979,800 sand and 1,860 bbl. of cement. You should have used at least 1,090,000 f sand showing a shortage of approximately 10%. Sand amount to t 40% of the pavement volume and a 10% shortage would account for a ncrease in the cement factor which checks the stone results given above.

ur batching apparatus consisting of steel sand hoppers and a steel le-gate blaw-stone batcher has been rated by me and found to be ct. The exactness of your routine batching, however, depends on the of your men and I have personally noted a number of cases where under s of time they were not completely filled. As a further evidence of essness in batching, your daily cement factor has ranged from 1.92 to The grade work has been excellent, and while minor inequalities in which it is impossible to prevent might account for a small variation, would not account for such a big range.

e outstanding facts are that you have not used enough sand and stone that it is evident that more care is necessary to prevent underrun in uring your sand and stone. It is not the function of the engineer or ctors to act as foreman for your men and prevent careless work. Our lies in calling your attention to conditions and in stating the maximum s of variations that we are willing to accept. We shall be pleased to you a daily statement of the cement factor but will hold you responsible ariations which exceed the ruling given in the first of this letter.

Sincerely yours,

Engineer in Charge.

BITUMINOUS CONCRETES

mounts of material, see pages 495 *and* 1143.

spection Details.—Two inspectors are required to handle the t work and the road work.

lant Inspection.—Plant inspection covers testing materials proportions of mix, checking temperatures, uniform feed of egates to drying drum, time of mixing, and certification of weights as the mix leaves the plant for the road.

lant Testing Equipment.—Plant testing can be carried out the following equipment:

of standard screens and sieves as may be called for in specifications requirements.
ff brush for cleaning sieves.
oratory stone balance (pan capacity 10 lb.).
oratory sand balance (pan capacity 100 g.).
netration machine with needles, glass dish, large pan for holding water and thermometer.
ddle and roll of manilla paper for pat test (for sheet-asphalt surface mixtures).
nored thermometers of suitable range for recording temperatures of the hot aggregates and mixtures.
pply of report forms.
pparatus should be properly housed in a separate building or room not less than 10 by 10′ and provided with a stool and work bench.

Sampling should follow the proposed methods of the Americ Society.

Samples.[1]—Samples should be put in clean, dry containe preferably tin boxes or cans. The following amounts of different materials are required for test:

	Poun
Stone, slag and gravel	5
Filler	½
Sand	1
Refined asphalt	1
Asphalt cement	1
Flux	1

Method of Sampling.—Extreme care should be taken in ev case to obtain a sample which is truly representative of the mate to be examined. These samples are for the use of the testing labc tory only and should not be used for testing at the plant bef submitting them to the laboratory. The particular precauti to be observed in each case are given below.

Stone, Slag, or Gravel.—A sufficient number of 5-lb. samples be taken from different parts of the pile. These should be tl oughly mixed together and reduced by quartering to the desired s

Filler.—Samples should be taken from several bags and mix

Sand.—Samples should be taken from the interior of the where the sand is damp. A sufficient number of 1-lb. samples be taken from different parts of the pile. These should be tl oughly mixed together and reduced by quartering to the desired s

Refined Asphalt and Asphalt Cement.—(*a*) In barrels: At le one sample should be taken from each batch. It should be ta at sufficient depth below the surface to insure obtaining represei tive material free from all dirt or other extraneous matter, and point not less than 4″ distant from the top and sides of the bai (*b*) In tank cars: The contents of the tank should be heated u completely liquid throughout. It should then be agitated thoroughly mixed by means of air or steam, after which the san shall be taken from the dome in such a manner as to obtain asphalt from a point at least 3′ below the surface. (*c*) In kett The contents of the kettles must be completely liquid and tl oughly agitated previous to and during sampling. The san may be taken from the pipe through which the material is delive to the mixer by means of a clean dipper.

Flux.—The directions given for sampling refined asphalt asphalt cement apply to this material except that under ordin conditions it is not necessary to agitate the contents of the tank

Surface and Binder Mixtures.—Samples should preferably taken on the street after the mixture has been shoveled and ral Samples taken from the plant shall be obtained from the wag special care being observed to avoid material from top of the l or which appears to vary from the average. Samples should pressed between a sheet of paper and trimmed while hot t convenient size. This is known as the pat test. The impres left on the paper is a fair guide as to the proper grading of the (see Figs. 344*A* to 344*D*).

[1] Adapted from proposed specifications for sheet-asphalt paveme A. S. M. E., 1922.

FIG. 344A.—About right amount of asphalt.

FIG. 344*B*.—Strong excess of asphalt.

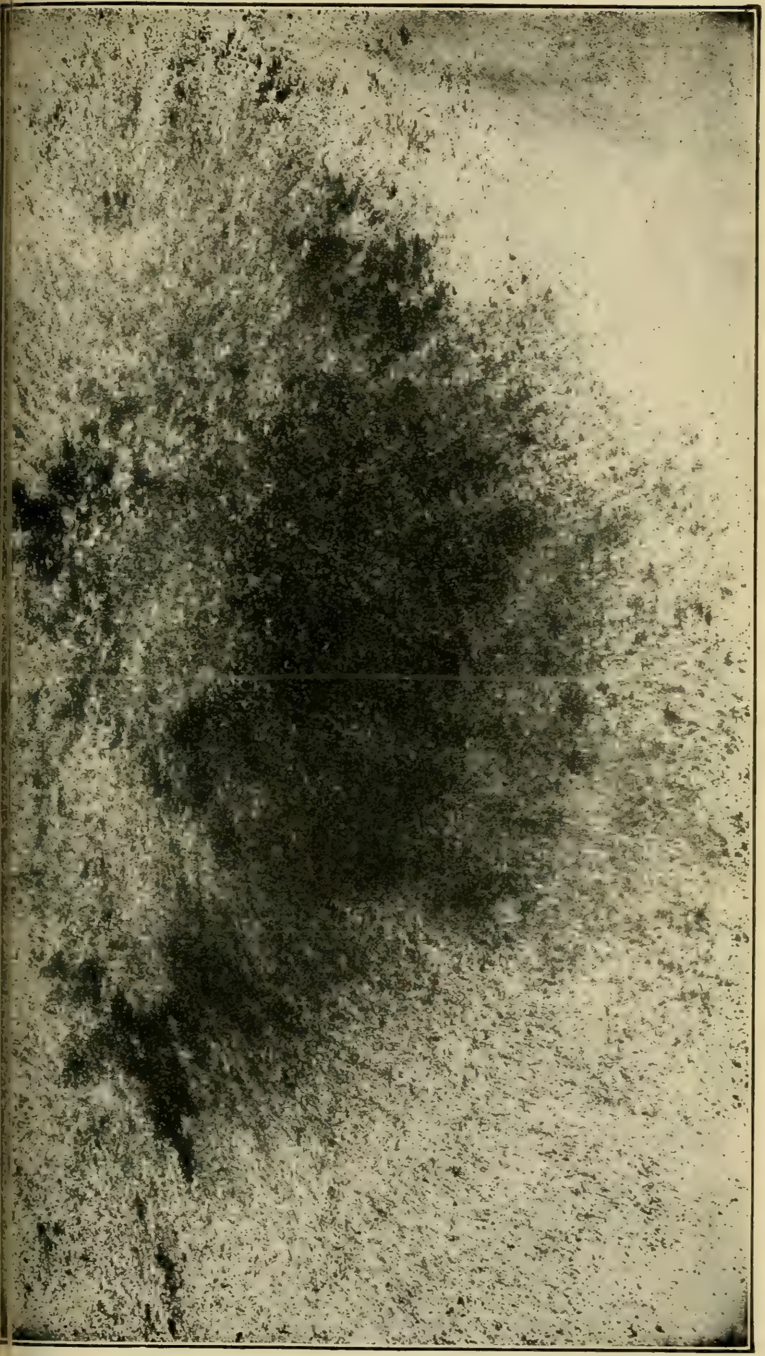


FIG. 344C.—Slight excess of asphalt.

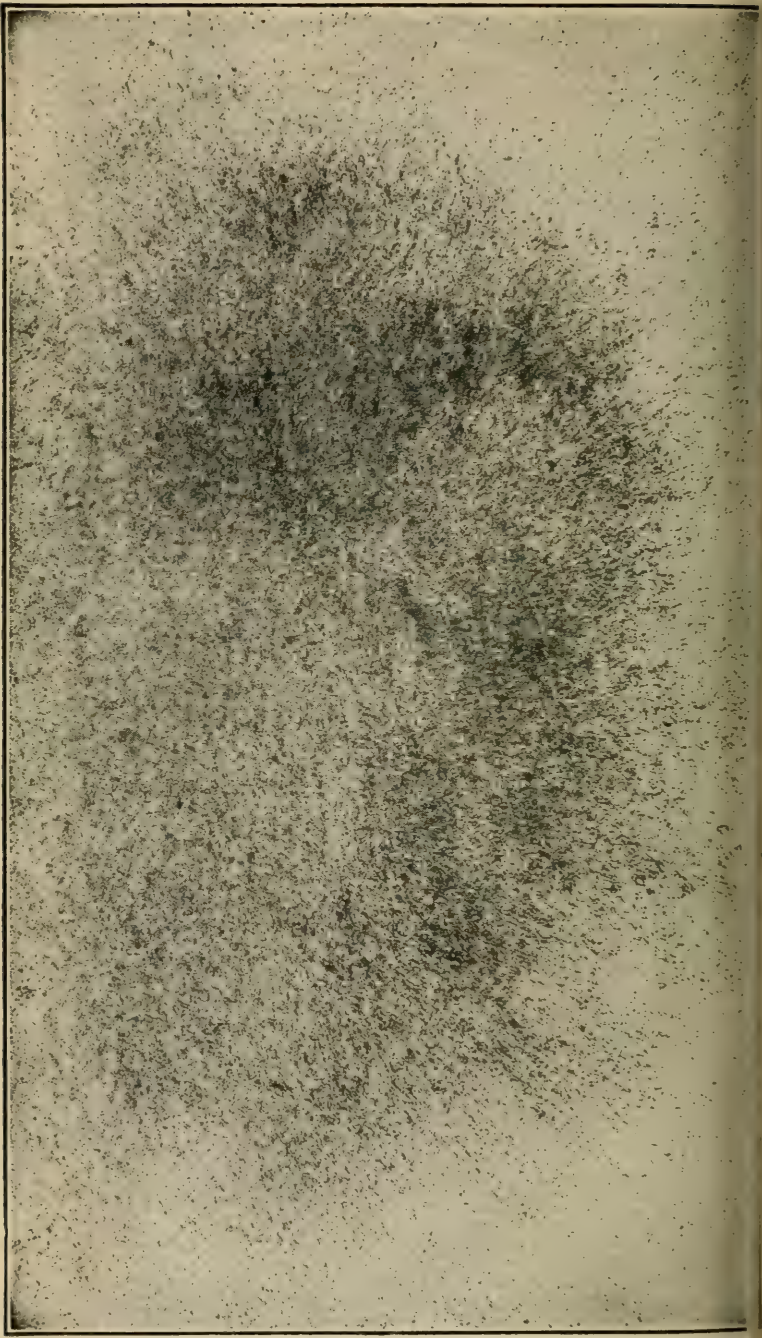


FIG. 344*D*.—Slightly deficient in asphalt.
FIGS. 344*A*, *B*, *C* and *D*.—Pat test illustrations. (*From Rich son's "Asphalt Construction for Pavements and Highways."*)

The pat paper test which is referred to above is thus described in Richardson's book "The Modern Asphalt Pavement."

"A small wooden paddle with a blade 3 to 4″ wide, 5 or 6″ long, and ½″ thick, tapered to an edge at one end and with a convenient handle at the other, is used to take as much of the hot mixture from the wagon as it will hold, being careful to avoid any of the last droppings from the mixer which may not be entirely representative of the average mixture. Samples of mixture should never be taken from the mixer itself, but only from the wagon after mixing is completed.

In the meantime a piece of brown manilla paper with a fairly smooth surface, 10 or 12″ wide, and torn off at the same length from a roll of this paper, which can be had at any paper warehouse, is creased down the middle and opened out of some very firm and smooth surface of wood, not stone or metal, which would conduct heat too rapidly. The hot mixture is dropped in the paper sideways from the paddle and half of the paper doubled over on it. The mixture is then pressed down flat with a block of wood of convenient size until the surface is flat. It is then struck five or six sharp blows with the block until the pat is about ½″ thick."

The paper will be found to be stained to a different degree depending upon whether there is a deficiency, a proper amount, or an excess, present. Examples of such stains are illustrated in the accompanying Figs. 334*A* to 334*D*.

Plant Analysis.—The proper proportions of aggregate are determined by analyzing the sizing of the different materials separately and then determining the proper proportion of each for the mix desired. A sample record of such work follows:

Proportions of Mix.—The proportions of mix should be determined by the engineer by screen analysis of the different materials that the contractor proposes to use.

As an example, assume that a mixture of cement, fine sand, coarse sand, and buckwheat stone is proposed and it is desired to determine the relative amounts of the different materials to use in order to get the correct proportion of sizes specified.

For all ordinary purposes a size analysis can be safely made using the following screens: 200, 80, 40, 10, ¼″ and ½″.

The materials are thoroughly dried and the percentages expressed by weight.

Fine sand (feeder pit) road 63	%
Passing 200	5
Passing 80 retained on 200	70
Passing 40 retained on 80	25

Good Quality

Coarse sand (Bauerman pit) road 63	%
Passing 200	1
Passing 80 retained on 200	2
Passing 40 retained on 80	29
Passing 10 retained on 40	68
Buckwheat stone (commercial plant) road 63	%
Passing 200	1
Passing 40 retained on 200	2
Passing 10 retained on 40	7
Passing ¼ retained on 10	60
Passing ½ retained on ¼	30

The proportions can now be varied to produce practically any required mix.

TABULATION SHOWING METHOD OF DETERMINING THE NUM
OF POUNDS OF EACH MATERIAL TO BE USED IN A 100-L
BATCH TO PRODUCE A REQUIRED MIX

Material	Number pounds	Bitumen	Mineral aggregate				
			200	80	40	10	¼ in.
Bitumen	9.5	9.5					
Cement	8.5	...	8.5				
Fine sand	33.0	...	1.5	23.1	8.4		
Coarse sand	33.0	...	0.3	0.7	9.6	22.4	
Buckwheat stone	16.0	...	0.1	0.1	0.2	1.1	9.7
Totals	100.0	9.5	10.4	23.9	18.2	23.5	9.7

NOTE.—The above mix used on Road 63 has served well for 12 years ı Class 11*A* traffic.

In this way the effect of varying any of the component ı of the mix can be readily seen and determined.

The total size of the batch is of course varied to suit the capa of the plant.

The laboratory analysis of the daily sample taken on the furnishes a check on the plant inspector.

The usual daily plant analysis consists of a mechanical : analysis of the hot aggregate as it runs into the batch box. varies much from the desired amount, the method of feeding various sizes to the drum should be changed. The proportic of the different sands and stones to the drying drum is often crudely done and results in a non-uniform aggregate. This not generally occur in large stationary plants but it is a freq source of trouble in small semiportable road plants.

Checking Temperatures.—Probably the most important of the plant inspector on road jobs is to prevent overheating o bitumen or stone aggregates, as most of our failures are dir traceable to overheating. In small semiportable plants, the stc bin for the aggregate is generally small and it is difficult to regı the heat of aggregate running directly from drum to batch small storage. The plant inspector must under no circumsta permit overheating which is generally set at 350°F.

Time of Mix.—Minimum time of mix recommended by Ası Association:

Binder course	30 sec.
Modified Topeka or sheet-asphalt surface	60 sec.

Record of Output.—A record of the weight and temperatu each load is made, see page 1323.

Field Inspection.—The inspection of grading, culverts, macadam bases are the same as discussed under Macadam, p 1272 to 1294.

The essentials of inspection of concrete paving base are the same as for concrete pavement (see pp. 1300 to 1313) in regard to subgrade, form setting, mixing, and placing except that the finishing requires different procedure and while the curing must not be neglected and requires earth cover and sprinkling, it does not require burlap or canvas covers immediately following the placing.

The surface of the concrete base must not show porosity or voids of any kind and the coarse aggregate must be imbedded, but a smooth, glassy surface is undesirable, as the binder coat does not get a good grip and tends to shove more rapidly into waves. The same care must be exercised to get a uniform crown and longitudinal profile, as depressions or humps in the foundation eventually produce an uneven surface due to the impossiblity of laying unequal-depth surface mix with the same degree of compaction. The surface mix must be uniform in thickness. City of Rochester, N.Y., Specifications limit the variation in depth of surface mix as follows: "The surface thickness shall not be less than 2″. Not more than 10% excess thickness will be permitted at any one spot."

Inspection of Laying Asphaltic Surface.—The inspection of laying and compacting the binder and surface layers of asphaltic concrete includes: approval of the condition of the concrete or macadam base, checking the depth of spread, temperature of mix as delivered, amount of rolling, and true shape of finished surface.

Condition of Base.—The base must have set a sufficient time and be well hardened. Specifications for the time of curing of cement concrete bases range from 7 to 21 days. Fourteen days is a reasonable length of time in warm weather, but should be increased to 21 days in the fall when the temperature falls below 50° on the average.

The base must be clean and free from dust, mud, organic deposits, or leaves. It should be broomed just prior to laying the asphaltic mix.

The base must not be wet. Slight dampness does no harm, but no asphaltic mix should be laid during rain or when the base has any pools of water or any snow on its surface.

Binder Course.—Binder should be laid only as far ahead of the surface as needed for keeping the work moving and should never be more than a day in advance of the surface mix. If such binder develops flaws such as poor bond or becomes broken up under traffic, it must be removed and replaced with fresh material.

Temperature of Mix.—The plant inspector is supposed to prevent overheating so that the usual point for the field inspector to watch is minimum temperature. This is generally set at 200°F. Once in a while a hot load gets by the plant inspector, which can easily be detected at the road, as the load will develop a heavy white smoke when dumped. Maximum temperature is usually set at 3[illegible]°F. at the street or 350°F. at the plant.

Thickness of Spread.—Thickness of spread is regulated by weight. Each driver is furnished by the plant inspector with a card certifying weight of load. This card is given to the field

inspector who regulates the distance (number of square ya that each load should cover. For all practical purposes, the o nary surface mix (Topeka) weighs about 105 lb. per square yard inch thickness of consolidated finished depth. The weight binder depends on the mix used; it is usually paid for by the and put on under a specification of a certain number of pounds square yard. The record of weight and surface area is illustra on page 1323.

The mix must be dumped ahead of the spread and enti rehandled by spreading by hot shovels and raked to final shape v hot rakes.

Joints.—All joints where work is stopped at noon or night m be cut back square vertical edges to full depth and painted v hot asphalt or a rope joint can be used. A lap joint ironed i not advised.

Rolling and Finish.—As soon as practicable, the surface sho be rolled with a light (3-ton) tandem roller and the final compres obtained with a 7- or 8-ton tandem. Rolling is important. requires not only the ordinary straight roll but also cross-rol to produce a smooth result. The maximum speed of rollin usually set at from 100 to 200 sq. yds. per hour for roller. finished surface should show no depressions or humps of over as measured by a 10′ straight-edge placed longitudinally to road.

The use of two rollers of different weights is desirable part larly in cool weather or on macadam bases. The light roller get on the hot mix quicker which prevents cracking likely to dev in cool weather due to the surface cooling much more rapidly t the body of the mix. Recent tendency in rolling calls for the of 3 wheel, 10 ton road rollers for compaction due to many case poor compaction with the use of tandem rollers with a consequ rough uneven surface after heavy trucking traffic produced f compaction.

The following quotation gives rolling specifications in detail:

Compacting Surface Course.—"While still hot, the surface course sha thoroughly and uniformly compressed by a power-driven tandem r weighing not less than 7 tons, except that initial compression may be obta by a power-driven tandem roller weighing not less than 3 tons. Ro shall start longitudinally at the sides and proceed toward the center of pavement, overlapping on successive trips by at least one-half the widt the roller. The pavement shall then be subjected to diagonal rolling in directions, the second diagonal rolling crossing the lines of the first. If width of the pavement permits, it shall in addition be rolled at right ar to the center line. Rolling shall be continued until all roller marks eliminated. The motion of the roller shall at all times be slow enoug avoid displacement of the hot mixture, and any displacements occurring result of reversing the direction of the roller, or by any other cause, s at once be corrected by the use of rakes and of fresh mixture when requi Rolling shall proceed at an average rate of not to exceed 200 sq. yds. hour per roller, and shall continue until no further compression is poss To prevent adhesion of the surface mixture to the roller, the wheels shal kept properly moistened, but excess of either water or oil will not be mitted. Before final compression a light uniform coating of limestone or Portland cement shall be swept over the surface of the pavement and rolling then continued."

PLANT RECORD, SEPT. 29, 1914

Load record				Bitumen record	
oad	Time	Temperature of mix, degrees Fahrenheit	Weight of load, pounds	Time	Temperature, degrees, Fahrenheit
1	7:30	320	5000	7:00	310
2	7:45	310	5000	8:00	345
3	7:55	300	6000	9:00	340
4	8:15	300	6000	10:00	310
5	8:25	290	5000	11:00	305
etc.	8:45	310	5000	12:00	320

ROAD RECORD, TEST SAMPLE 7, SEPT. 29, 1915

d	Time	Temperature of mix, degrees Fahrenheit	Weight as per ticket, pounds	Number yards covered	Location on road
	8:00	310	5000	25	Sta. 10 + 30 to 10 + 42
	8:20	300	5000	25	Sta. 10 + 42 to 10 + 54
	8:30	295	6000	30	Sta. 10 + 54 to 10 + 69
	8:45	295	6000	30	Sta. 10 + 69 to 10 + 84
c.	9:00	280	5000	25	Sta. 10 + 84 to 10 + 96

e following report on a Topeka mix resurfacing job in New State illustrates a specific case where part of the work was actory and part unsatisfactory.

)RT FOR DIVISION ENGINEER ON REPAIR CONTRACT ——

July 9, 1925

——

Sir:

accordance with your instructions of July 1 I have made a thorough nspection of the contractor's equipment, construction operations, and eted work on Repair Contract —— with special reference to complaints in regard to this job. The inspections were made July 2 and 4, at time the pavement had been completed from Sta. 191 to 288, Road –. ırface roughness of the pavement was tested by means of a 10′ straight-by riding over the pavement in a Ford car, Essex Coach (balloon tires), adillac car at speeds from 20 to 40 miles per hour. Local people were iewed as to how they liked the pavement, and it was examined after l rain for pools of water. The stability of the edge of the black base ested by driving loaded trucks (24,000 lb.) along the side of the base m the edge. Cross rolling was checked up by inspection of the rolling. ant and laying equipment was checked over and all operations checked nperatures, time studies, etc. Materials were inspected and check sieve sis made.

nplaints were evidently based on the first 1500′ of pavement which iewhat rougher than desirable. It took the inspectors and contractors' this distance to solve the special difficulties of manipulation due to alities of the old pavement. From Sta. 206 to 288, the pavement being laid shows a smooth-riding surface. I would class this job as

a whole including equipment and manipulation as a good average jol while it cannot be classed as of the highest grade, there is no basis for an that either the department or this type of pavement will be discredit account of poor workmanship. As a matter of fact, the local peop enthusiastic over the type of pavement and the job as a whole.

It is, however, probably desirable to make a few minor changes below and it is certainly desirable at this time to consider future change additions to the existing specifications to bring them up to a first standard. Most of the following recommendations cannot be enforced the existing specifications if the contractor objects.

Recommended Changes Repair Contract ——

Design changes.

1. Construct a bituminous (binder) flush edging 1½″ deep 6″ wi both sides of the top course to prevent crumbling of edge. This has al been recommended by the engineer in charge and is essential fc success of the pavement. The contractors have agreed to do this at l prices, but they consider it a favor at this price and they will probably some return favors amounting to about double what a reasonable su mentary agreement price would be.

2. Bridge over small pipe culvert trenches with cement-concrete slabs to prevent settlement and disagreeable bumps developing. T common city practice and will tend to prevent a general criticism type from the ordinary road user.

Contractors' Equipment and Manipulation.

1. Side forms to be solidly pinned down with top of pins flush with form to permit proper cross-rolling. At present the wooden side forn loosely held by long pins on the outside edge which stick up above the and prevent good cross-rolling. Quite frequently the roller hits these loosens the form, shoves it out of line, and causes bad hair cracks alo edge (see specification discussion). This recommendation cann enforced under existing specification if the contractor objects wit supplementary agreement. It may be desirable to construct the bitur flush edging ahead of the surface mix, which would simplify the form pr and dispense with special forms when laying top course. This m worth trying but will require a special price supplementary agreement

2. A three-wheeled 10-ton standard roller should be used to conso the first spread of black base in pot holes and along the edge of t macadam. At present a tandem roller is being used and there is no bility of its being really effective for this first layer (see specificatio cussion). This recommendation cannot be enforced under present s cation.

3. Three rackers should be used to spread top. At present only tv used, and while it may be possible for these men to produce a surface meets our minimum requirements, it is certain that a much better s would be obtained with an additional racker (see specification discu This recommendation cannot be enforced under present specification

4. Rollerman should be required to keep moving at least 8 hr. out and to roll for at least 30 minutes, after the rackers stop at nigh specification discussion). This recommendation cannot be enforced present specification.

5. Overflow pipes should be provided for both sand and stone s compartments on mixing plant to prevent mixing of sizes. At p the sieve analyses show that at times the stone hopper dis contains 40% of sand; 15% is the usual maximum limit (see specifi discussion). This recommendation cannot be enforced under p specification.

6. Correctness of plant scales should be tested and certified by sea weights and measures.

There is no reason to doubt these scales but a large amount of bir paid for by weight, and it is just as well to have a certificate of correctn

7. Insist on a minimum time of mixing for top course of 60 sec. per Present time varies from 35 to 50 sec. (see specification discussion). recommendation cannot be enforced under present specification.

8. At least 50 lb. of commercial mineral filler should be used per 10 batch of top mix and the amount of asphalt increased from 85 to abo lb. per batch. At present no filler is used. The present mix used fo shows an excellent grading except for fine stuff. The desirability c

mendation can be easily checked by referring the matter to the alt Association or to the city testing engineer, Mr. ——. This recom-ation can be enforced, but the contractors will probably ask you to it to balance up their favor to you in constructing the new edging at r prices. They never will be really willing to use the proper amount of until it is paid for as a separate item.

Fill pot holes and place edge-widening strip for at least 1 mile ahead of ar binder and surface spread to permit better compaction of this layer.

gineering Recommendations.—1. Have an inspector on the scale plat- to check weights for binder paid for by the ton.

Provide necessary screens, drying outfit, and scales to permit engineer ke daily check analyses of mineral aggregate.

Recommended Changes in Specifications

rtain changes are recommended in the 1925 specifications. Our nt specifications are a distinct improvement over the 1923 specifications matter of grading of the mineral aggregate and use of mineral filler but are still weak and indefinite on a number of points of equipment, and pulation details which are necessary to insure thorough and uniform g, spreading, and rolling. To illustrate these points, the following compares the best prevailing practice with our 1925 specifications and hows how Repair Contract —— compares with both the best practice ocal Specifications.

ave looked over most of the hot-mix jobs in this locality during con-tion for the last 15 years and in my opinion there has never yet been lass work done on a state road in this vicinity. The contractors always on taking advantage of the weakness of these specifications, and while do a moderately good job, the tendency has always been to cut down on d mineral filler, to mix the batches too short a time, to rake carelessly, derroll, and to cut quite fine on the weight per sq. yd. of surface mix.

nsidering that this type of pavement is a logical and economical solution considerable mileage of reconstruction, it is certainly desirable to use a ication which will permit the engineers to force a first-class job in case pute.

COMPARISON OF SPECIFICATIONS AND PRACTICE ON REPAIR CONTRACT ——
Compiled by W. G. Harger, July 7, 1925

Item	Best specification practice, 1925	Local 1925 specifications	Practice on Repair Contract ——	Recommended changes Repair Contract ——
Mixing Plant Items				
Minimum capacity of mixer	10 tons per hr. surface mix	No mention	10 ton normal capacity 12 to 14 tons per hr. surface mix	Plant is being crowded
Minimum size of batch	1000 pounds	No mention	1000 pounds	O. K.
Type of kiln dryer	Rotary	Rotary	Rotary	O. K.
Temperature measurement of hot aggregate	Pyrometer	No mention	Pyrometer	O. K.
Screen for separation of hot aggregate.	At least 2 sizes	....	2 sizes	
	Passing No. 10	....	Passing No. 10	
	Retained No. 10	....	Retained No. 10	
	Reject retained ¾″	No mention	Rejects	O. K.
Minimum number separate storage compartments, hot aggregate	2	No mention	2	O. K.
Overflow pipes from separate bins	Required	No mention	None	Should be provided
Maximum carry over of sizes in storage bins	15%	No mention	10% to 45%	Excessive at times
Type of scales to weigh aggregate	Standard lever scales with 2 bar control	No mention	Standard	O. K.
Certificate of scale accuracy	Sealer of weights and measures	No mention	Have not been tested	Should be tested
Type of mixer	Twin Pug	Revolving blade	Twin Pug	O. K.
Maximum clearance end of mixer blades to lining of drum.	Surface mix ⅜″ Binder 1″ Surface and binder combined ½ to ⅝″	No mention	1¾″	Rather excessive but seems satisfactory
Minimum time of mix per batch:				Not mixed long

Item	Best specification practice, 1925	Local 1925 specifications	Practice on Repair Contract ——	Recommended changes Repair Contract ——
Number asphalt kettles	2	No mention	2	O. K.
Method of heating asphalt	Steam	No mention	Steam	O. K.
Asphalt temperature measurement	Thermometers	Thermometers	Thermometers	O. K.
Range in temperatures of hot-mix aggregate	275 to 350°F.	225 to 300°F.	225 to 330°F.	O. K.
Range in temperature (asphalt)	250 to 350°F.	275 to 325°F.	260 to 320°F.	O. K.
Daily sieve analyses of mineral aggregate firm Hopper shoots.	Required	No mention	None	Should be made by engineer
Proportions of mix	See special discussion at end of report			
Hauling and laying items				
Covers on loads	Required in cool weather or long hauls	Required	Not used for short hauls warm weather	O. K
Maximum amount dumped ahead of rackers	6 tons	Not mentioned	5.5 tons	O. K.
Spreading equipment	Heater, smoothing iron tamping irons, shovels and racks	Necessary	O. K.	O. K.
Maximum rate of spreading per racker	33 sq. yd. per hr.	Not mentioned	2 rackers used 60 to 90 sq. yds. per hr. per racker	Needs three rackers for good work
Tamping along edge	Required	Required	Tamped	O. K.
Temporary edge forms	Timber strips firmly spiked with top of fastener pins flush with top of form to permit cross-rolling	Not mentioned	Timber strips poorly fastened by long pins which prevent proper cross-rolling	Improve existing side forms

COMPARISON OF SPECIFICATIONS AND PRACTICE ON REPAIR CONTRACT ——.—(*Continued*)

Item	Best specification practice, 1925	Local 1925 specifications	Practice on Repair Contract ——	Recommended changes Repair Contract ——
Type of roller binder course........	10 ton 3 wheel or 8 ton tandem as ordered	8-ton tandem	Three-wheel 10-ton available but not used. 8-ton tandem used all rolling	Use three-wheel 10-ton roller for first course of binder. 8-ton tandem O. K. for balance of work
Surface course....................	7–8 ton tandem for finishing; 5-ton tandem for initial compression	8-ton tandem	8-ton tandem	O. K.
Maximum permissible amount of rolling per hr. per roller surface mix.	100 to 150 sq. yd. per roller per hr.	Not mentioned	170 to 200 sq. yd. per hr.	Roller should be kept moving continually and should roll for at least ½ hr. after rackers stop
Testing surface with 10′ straight-edge..........................	Required	Required	Tested by inspector	O. K.
Repair of depressions.............	Immediately after initial compression	Not mentioned	Repaired at once	O. K.
Cement coat......................	Required	Required	O. K.	O. K.
Minimum weight surface mix per sq. yd. for 1½″ finished depth....	155 to 160 lb. per sq. yd.	Not mentioned	157 lb. per sq. yd. according to batch weights	O. K.

...SSION OF SURFACE MIX GRADING AND SIGNIFICANCE OF LABORATORY TESTS

L oratory analyses of the finished mixture are not a very reliable basis termining the actual composition of the pavement except for the tage of bitumen which is quite reliable considering the average of a r of samples.

T safest means for designing the mix and determining the best batch tions is by the use of daily sieve analyses of both the raw products they enter the drying drum and sieve analyses of the sand and stone ts as they are discharged from storage bins into the mixing hopper. rst analysis determines the approximate proportion of sand and stone fed to the drying drum and the second analysis determines the final ng proportions and the amount of mineral filler required for a good mix. O epair contract —— the sand used is supplied by George Amish. It is uniform product. The stone used is a mixture of Dustless screening one dust. This product is furnished by the Le Roy Limestone Com- It is a good product but fluctuates considerably in composition. The is of these two materials is attached. An examination of these sieve es taken July 2, 1925, indicates that they should be fed to the drying n the proportion of about 1 part stone to 2 parts sand. This is the tion being used and is satisfactory.

e analyses of the Hopper feed of hot sand and stone are attached , 1925).

T batch proportions being used are 265 lb. of Hopper feed stone, 650 lb. of r feed sand and 85 lb. of asphalt. Using these proportions and the Hop- alyses of sand and stone of July 2, we get the following grading for the ix. This tabulation also shows the ideal mix for conditions similar road (see Chapter VI, page 501). It can be readily seen that the mix unusually good except for a shortage of fine material (pass 200 mesh) can be easily added as bagged mineral filler.

	Mix in use Repair Contract —— July 2, 1925, %	Ideal mix, %
...nen	8.5	9.0
...ng 200 mesh	4.6	9.0
...ng 80 mesh	14.1	14.0
...ng 40 mesh	37.8	25.0
...ng 10 mesh	13.6	21.0
...ng ¼ sieve	14.8	15.0
...ng ½ sieve	6.6	7.0
...tal	100.0	100.0

O e basis of this analysis I recommend that at least 50 lb. of commercial l filler be used per batch and that the asphalt be increased to about lb. as determined by trial.

T laboratory analyses of the finished product consistently show from 9.8 % of bitumen, while the scale proportions indicate 8.5 %. As the ination of bitumen is quite accurate, this indicates the possibility e plant scales are incorrect or that there is a consistent shortage of 50 b. per batch in weighing the mineral aggregate. This is not a severe ancy, but it indicates that it is desirable for the plant inspector to me track on the weighing operations, particularly for binder where it for by weight.

Hopper Feed Analysis

	Sand, %	Stone, %
Retained on ¼″	..	26
Retained on 10	..	56
Retained on 40	15	14
Retained on 80	58	1
Retained on 200	21	1
Pass 200	6	2

Raw Products

	Sand, %	Stone, %
Retained on ¼″	1	7
Retained on 10	7	43
Retained on 40	15	32
Retained on 80	42	7
Retained on 200	26	5
Pass 200	9	6

Binder Course

Grading of Aggregate.—The binder is batched 250 lb. of sand, 65 stone, and 45 lb. of asphalt. This is a satisfactory mix which works the pavement.

The binder (black base) is spread and compacted in two or three depending on the inequalities to be taken out.

At present each layer is being compacted by the 8-ton tandem This roller is not suitable for compacting the first layer which fills holes and widens the old macadam by a narrow side strip of varying I recommend that a standard 10-ton three-wheel roller be used in com this first layer. The tandem roller is satisfactory for the top layer of

Criticism has been made that the binder was not properly compac was it protected from side shore by a firm earth shoulder. The base laid shows no evidence of either side shove or rutting when 24,000-lb loads are run along the edge. It is probable that continued heavy may compact this edge in the future somewhat and increase the slightly, but I have no hesitation in saying that an earth shoulder of t soil available would have no effect in improving the stability of thi The stability of the edge must depend on the stiffness of the bla itself. We have recommended the use of a three-wheel roller to m future settlement, under continued heavy traffic.

It is desirable to fill all pot holes and place the side-widening s at least 1 mile ahead of the regular binder and surface spread to get a compaction by rolling and traffic. This evener layer should be well pc

Signed

W. G. Harger.

BRICK PAVEMENT

Amounts of material, see pages 511 *and* 1146.

"**Inspection Details.**—The success of a brick pavement de largely on the care in construction and rigid inspection. Insp covers careful control of grading, culvert backfills, concrete and brick surface. Inspection methods for all operations the brick surface have been previously discussed.

"Brick surface inspection includes control of handling cushion, laying, culling, rolling, grouting, and protection un

Suggestions published by the Dunn Wire Cut Lug Brick Company are definite and reliable as any source. They are quoted as follows:

Expansion Joints.—Expansion joints shall be placed parallel with and at each curb line and extend across each street and alley intersections. It should be ½″ in width for streets less than 20′ wide; ¾″ for streets from 20 to 30′ wide, and 1″ in width for streets wider than 30′. This joint must extend to the depth of the brick.

A premolded or prepared bituminous strip which will be unaffected by the action of water and will remain pliable at all temperatures to which it may be subjected shall be used for this purpose. The material should be made into strips of suitable length and of the required depth and thickness and shall be placed in the pavement with the ends closely joined as the bricks are being laid.

Delivery of Brick.—Before the grading is finished, the brick shall be hauled and neatly piled outside the curb line in sufficient quantities to complete the brick surface. Clamps or conveyors may be used in connection with this work, but the brick shall not be dumped from wagons to piles, or from cars to wagons, nor shall they be piled in any location where they are likely to become bespattered or covered with mud or otherwise injured, unless thoroughly protected.

In delivering the brick from the piles for placement in the street, no wheeling in barrows will be allowed on the brick surface. The work shall be so arranged and carried on a pallet, or conveyor, that when delivered to the dropper, each brick, in the regular operation of placing upon the cement-sand bed as prepared, will naturally lie with the projections in the same direction and with the best edge uppermost.

Cement-sand Bed.—Upon the foundation as prepared there shall be spread a bed of cement and sand of uniform density to the depth of 1″ and in the proportion of 1 cement and 4 sand. The cement and sand shall be thoroughly mixed dry in a mixer until a uniform color is obtained.

The cement-sand bed shall be carefully shaped to a true cross-section, parallel with the finished pavement, by means of a template covering at least one-half of the width of the brick work, and so made as to be easily drawn over the curb or guide rails set to the proper elevation. The operation of shaping the cement-sand bed for the brick is considered of prime importance in securing the desired evenness in the surface of the finished pavement.

Brick Laying.—Upon the cement-sand bed as prepared, the brick shall be immediately laid with the best edge up, the projections in one direction, and with the courses straight and at right angles to the center line of the pavement, except in the case of hillside brick which are to be laid parallel thereto. All joints must be broken at least 3″, and the courses straightened by tapping lightly with a sledge on a 4 by 4″ timber 3′ in length, provided for that purpose. Nothing but the whole brick shall be used except in starting and finishing courses, or in such cases as may be directed by the engineer. The cutting and trimming of the brick shall be done by

experienced men. For closures, nothing less than 3″ bats sha used, and the fractured ends laid toward the center of the pavem Broken and chipped brick suitable for batting shall be used sc as practical in obtaining the necessary half brick for brea course and making closures, instead of breaking otherwise w and sound brick. All brick when laid shall be clean and clean and entirely free from dirt or other foreign matter until pavement is completed. All the work of brick laying shal done over the brick already laid. The disturbing of the prep cement-sand bed is prohibited. As soon as any surplus of deli of brick is ascertained, they shall promptly be moved forwar use.

"After the brick have been laid, the chips shall be swept fron street, all soft brick removed, and those badly broken, b spawled, or misshapen shall be turned over or removed by contractor. Brick slightly chipped for batting in shall be ca forward and used for that purpose; the remainder shall be pl in separate piles along the street. The inspector shall keep brick culled, and the contractor shall make the necessary cha and replacements so that the work at all times shall be read the grouting within 50′ of the brick laying.

"After the brick are laid the contractor will start culling. you and your inspectors should carefully go over them, mar all soft[1] bricks to be taken out and rejected; all kilnmarked b to be turned over, and if not satisfactory to be taken out and for pinning in; all overburned bricks,[2] which are burned to a ci to be rejected. All underburned bricks, which, in your opi will not make a satisfactory pavement, to be rejected. All bro bricks (which have the appearance of overburned brick but on one side only) to be turned over, and if satisfactory allow remain in the pavement.

"Be sure that you have culled all of the bricks before the p ment is rolled, for after the pavement is rolled if much culli done you are liable to have a rough pavement. After the p ment is rolled go over same and mark all broken and sp bricks, to be taken out or turned over.

"Be careful of all high and low bricks in the pavement, for will wear badly when the road is finished.

"Be sure that your bricks are laid at right angles to the and are not wavy as to line.

"In no case allow any 'Dutchman'[3] in your pavement ex on curves where absolutely necessary.

"**Rolling.**—Immediately after the brick in the pavement been inspected and the surface of the pavement swept clea shall be rolled with a self-propelling tandem roller, weig approximately 3 tons, in the following manner: The rolling

[1] Soft brick are found by sprinkling the pavement lightly; the sc under-burned brick will absorb the moisture, rapidly becoming dull, the good brick still glisten with the water.

[2] Over-burned brick are known by their color, which is much darker the average.

[3] "Dutchman." Brick chipped to wedge shape to fill in between courses on curves.

mence near the curb or edging line, at a slow pace and continue k and forth until the center of the pavment is reached, then s to the opposite curb or edging line and repeat in the same nner to the center of the street. After the first passage of the er the pace may be quickened. The pavement shall then be ed transversely at an angle of 45°; repeat the rolling in like nner in the opposite direction, then roll parallel with the curb dging line until the surface is smooth.

Before this last rolling takes place, all broken or injured brick st be taken up and replaced with acceptable ones. Portions he pavement inaccessible to the roller shall be tamped to grade he use of a hand tamper applied upon a 2″ plank.

After the final rolling, the surface shall be tested with a 10′ ight-edge laid parallel with the center line of the pavement and depressions exceeding ¼″ shall be taken out.

All brick laid shall be rolled ready for grouting at the end of the king day.

Cement Grout Filler.—The cement grout used in filling the joints e brick shall consist of 1 part of cement and 1½ parts of sand.

The cement shall meet the requirements of the Standard Specifi- ons for Portland Cement of the American Society for Testing erials, adopted Aug. 16, 1909, with amendments and additions eto adopted by the said society.

The sand for the cement-sand bed and the grout filler shall be posed of clean, sharp, well-graded quartz grains and shall not ain more than 5% of clay or silt. The grains shall be such size all will pass a No. 12 sieve and that not more than 40% will a No. 50 sieve.

s soon as the pavement is rolled and before the filler is applied, pavement shall be thoroughly saturated with water so as to e the hardening of the cement-sand bed. The brick must be when the grouting starts.

he cement and sand for grouting in correct proportions shall horoughly mixed dry until the mass assumes a uniform color. this mixture a small batch not exceeding 2 cu. ft. shall be d in a suitable box or a machine especially adapted for that ose. Slowly add water and thoroughly mix until the mixture such a consistency that it will readily flow into the joints out separation. Ample time must be taken in preparing liquid mixture, first making a plastic mortar, then gradually ing by mixing and slowly adding water; continue the mixing all is removed and applied to the surface in small quantities. application should be continued until the joints appear to be Any surplus material remaining on the bricks shall then ept into the joints. Extreme care must be taken that the are not cemented over and that the filler extends down to the m of the brick.

fter the first coat has had a chance to settle and before the l set develops, a second coat shall be applied in a similar er with a somewhat thicker grout. After this application ad time to settle and before the initial set takes place, the nent shall be finished to a smooth surface with a squeegee

having a rubber edge which shall be worked over the brick at angle with the joints, thus leaving them entirely filled.

"The contractor shall provide thin metal strips $1\frac{1}{16}''$ by 6" 3' long and insert same in the brick joints across the street w closing up a stretch of grouting at work intervals, so that grouting will end in a vertical joint. These strips must be ta out when the grout becomes stiff and before the initial set.

Protection of Filler.—After the surface has been thoroug inspected and if approved, and sufficient time for setting has ta place so that a coating of sand or earth will not absorb any moist from the cement mixture, the surface shall be covered with 1' more of sand or earth to prevent too rapid drying of the fi This shall be kept moist for at least 4 days, and no traffic shal allowed on the street for a period of at least 15 days.

Hillside Brick.—On grades, when ordered by the engin standard hillside brick shall be used. These brick shall in qua and test conform to the requirements of these specifications.

The general method of constructing a wire-cut lug hillside pa ment shall conform to the standard specifications, except that bricks shall be laid longitudinally instead of transversely. T shall be grouted in the manner specified for brick pavem except that all grout in the surface grooves of the wire-cut lug hil brick shall be broomed out before it shall have time to set up (being taken not to disturb the grout in the longitudinal joi This brooming shall be done transversely with a rattan broom.

Note.—We strongly advise the use of a small mixer prop equipped for applying the grout. This mixer should be use the first application, and a suitable box for the second applica When boxes are used the grout shall be removed from the same scoop shovels.

Bituminous Filler.—Where bituminous filler is used, the l must be clean and dry when the filler is applied. It must be he to the proper temperature between 300 to 380°F. and applie either conical pouring cans the nose of which rests on the and is drawn along the joint, or by the squeegee method. squeegee method is recommended by the brick people. In method the hot filler is poured on the pavement and rapidly wo into the joints by hot iron squeegees operated slowly back and forward at an angle with the joints. The operation is conti until the joints remain full and a thin film of bitumen remai the surface of the brick. A thin sand or screening coat is sp over the surface and the pavement opened for traffic.

BRIDGES

Staking Out Bridges.—Bridge abutment and superstru plans are usually quite thoroughly dimensioned and these di sions refer to the center line of the finished bridge and to the span between faces of abutments or between bearing centers

Abutments are usually staked out for construction by m of two or more firmly driven center-line stakes placed outsi the limits of excavation and at a known distance from the

the abutment and also by offset side stakes outside the limits of excavation at equal distances from the face of the abutment to

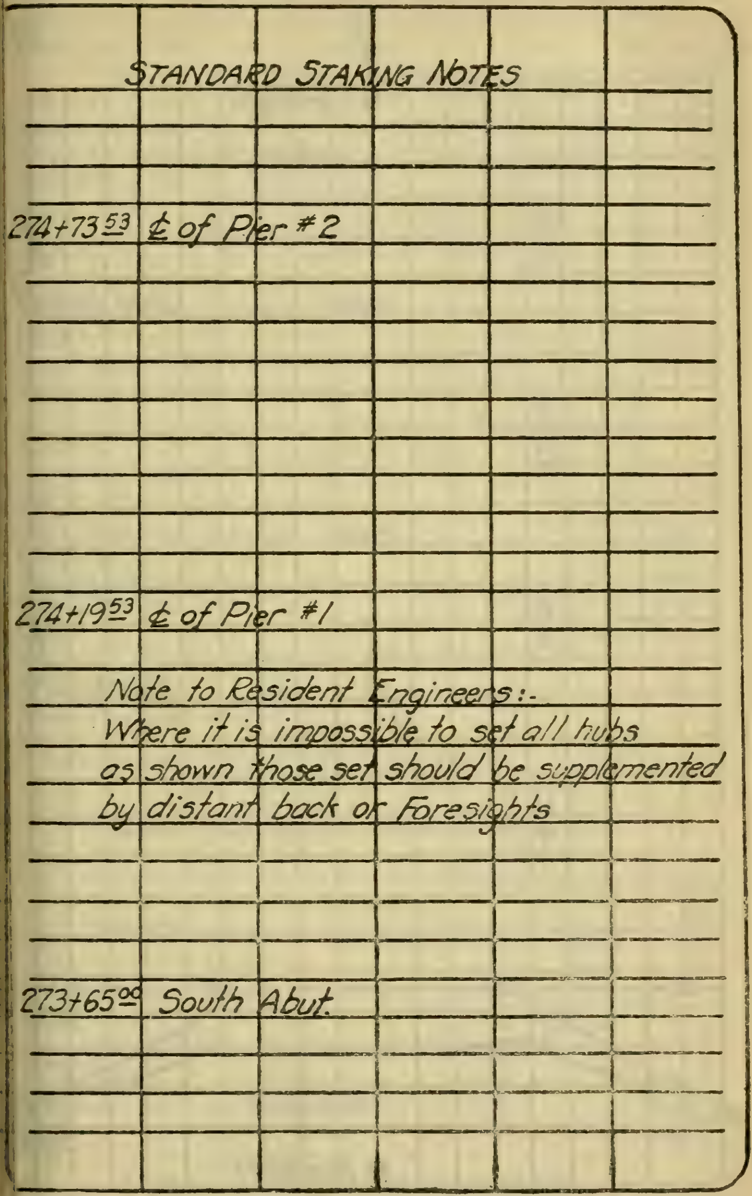


FIG. 345.—Bridge staking notes.

establish the location and angle between the road center line and the face of the abutment; the location and direction of the face

of the wings are shown by special wing stakes. Figure 345 sh
the usual method which is modified to fit special conditions. T

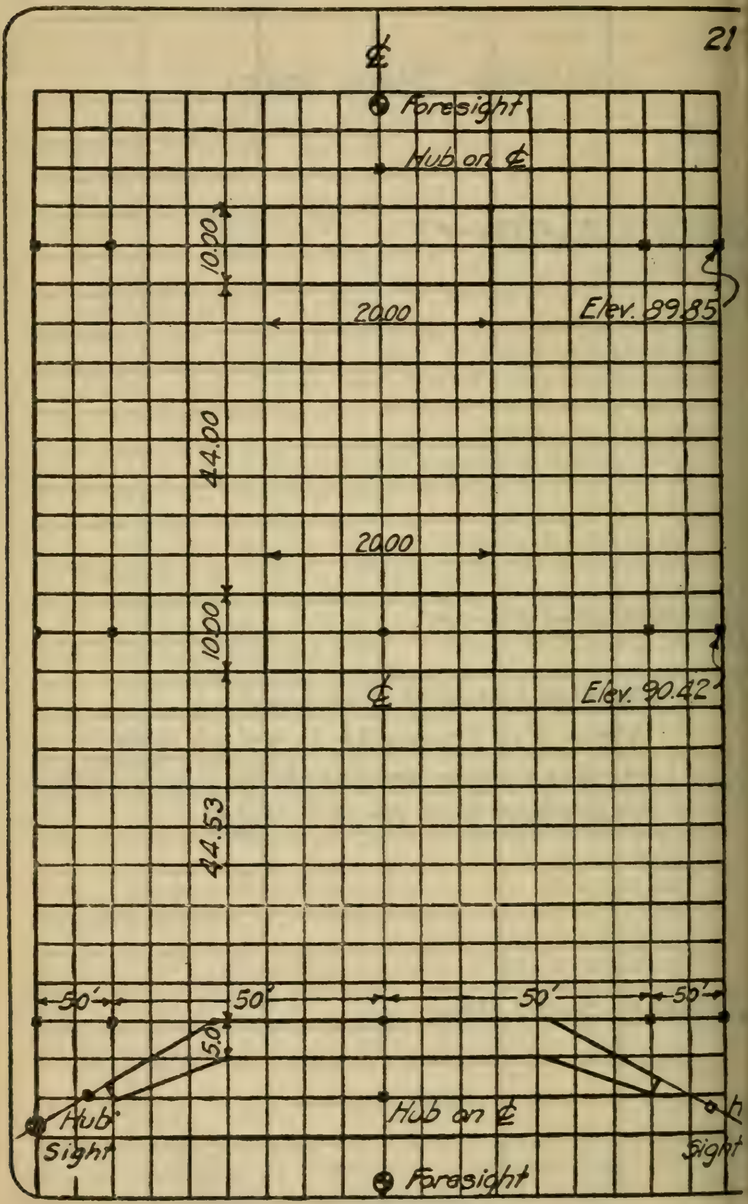


FIG. 345.—(*Continued*).

elevation of the top of all these stakes is determined from wh
the grade of the foundations, bridge seats, camber blocks, etc.

bireadily determined. A permanent bench mark is established in he immediate vicinity.

earing Power of Foundation Soils.—The foundation pit is exvated to the lines and grade shown on the plan and the charac-teof the soil determined not only for the bottom of the pit but al for at least 10′ below the bottom by bar and gas-pipe core saples to be certain that the underlying strata does not materially clnge the safe bearing of the soil encountered at the grade depth. A bridge abutment plans should show and generally do show the be-pressure diagram which gives the maximum toe and heel prsure for the completed structure (see Fig. *A*, p. 1047). The sa bearing power of soils is a very indefinite proposition and all asimptions should be conservative. While actual test loads ca be applied, this is rarely necessary for the usual highway bridge ar the final decision as to the width of spread, footing, or the use of iles is based on the allowable pressures, discussed on pages 207 to 09 and repeated at this point in tabular form. Table 232 shows th result of actual tests for settlement on common soils.

TLE 231.—RECOMMENDED MAXIMUM PRESSURE ON BRIDGE FOUNDATION SOILS

Cln dry sand	2 ton per sq. ft.
Cined sand and fine gravel	3 ton per sq. ft.
Crse gravel	4 to 5 ton per sq. ft.
Oinary mixture sand and clay	2 ton per sq. ft.
Sd damp clay	1 ton per sq. ft.
D clay thick layers	3 to 4 ton per sq. ft.
Cented gravel and hard pan	6 to 7 ton per sq. ft.
Sd rock	8 ton per sq. ft.
Hd rock	20 ton per sq. ft.

OTE.—Arch bridges require piles unless the foundation soil is rock or ha pan.

tual Test Loads.—Safe load is generally considered as 50 % of actual lo producing a settlement of ⅛″ in 48 hr.

TABLE 232.—ACTUAL PRESSURES ON DEEP FOUNDATIONS (E. S. Corthell)

Material	Number of examples	Pressure in tons per square feet		
		Maximum	Minimum	Average
Actual pressures which showed no settlement				
ne sand	10	5.4	2.25	4.5
arse sand and gravel	33	7.75	2.4	5.1
nd and clay	10	8.5	2.5	4.9
uvium and silt	7	6.2	1.5	2.9
rd clay	16	8.0	2.0	5.08
rdpan	5	12.0	3.0	8.7
Actual pressures which showed settlement				
ne clay	3	7.0	1.8	5.2
ay	5	5.6	4.5	5.2
uvium and silt	2	7.6	1.6	
nd and clay	3	7.4	1.6	3.3

The method of reducing toe pressure by increasing the wi of the footer course is explained on pages 1047 to 1049. If the any uncertainty as to objectionable settlement, piles should be u as it never pays to take a chance on foundation stability. P should also be used if there is danger of excessive scour, eve the soil is safe from the standpoint of bearing value.

Test Piles.—If piles are shown on the plan or become necess on account of unexpected foundation soil conditions, test piles driven to determine the length, number, and spacing of piles be ordered driven.

At least six test piles should be driven located at the cente each abutment and at the ends of the wings to determine varia in conditions which are likely to occur.

These piles are driven to a satisfactory resistance. There two general conditions; first where the pile is driven to rock hardpan strata and where the top material is semifluid and soft; in which case it is figured as a long column and for wh blunt-end or blunt-point piles are required (see long column ta p. 1078); second, where the pile develops a safe load by skin fric between pile and soil, in which case the length size and taper con the safe load which is increased by length and size.

The safe load in friction piles can be closely determined only actual test loads and is usually specified as 50% of the actual l causing a settlement of ⅛″ in 48 hr., but as a general rule so-called *Engineering News* formulas which are based on exter experience and tests will serve as a safe criterion of safe l These formulae are given below and are supposed to give a facto safety of 6 although Table 233 comparing actual observed computed loads shows considerable range of results.

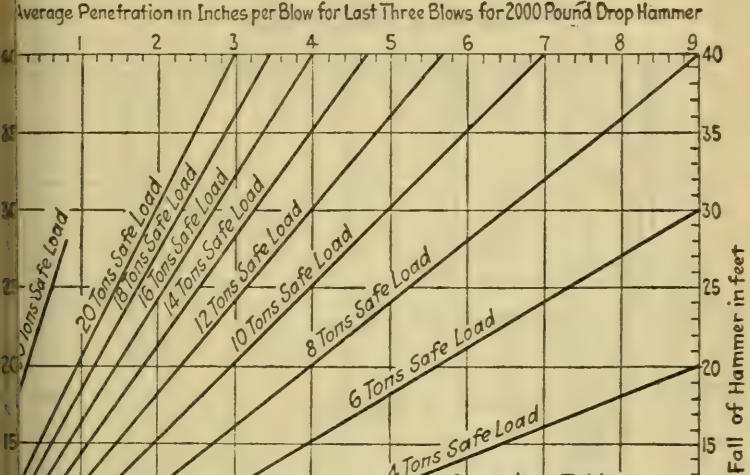
TABLE 233.—COMPARISON OF ACTUAL AND COMPUTED S LOADS ON PILES[1]
(*Engineering News* formulas—drop hammer)

Length of pile, feet	Weight of hammer, *W* lb.	Height of fall, *h* ft.	Last penetration per blow, *S*″ inches	Load		Character of soi
				Observed	Computed	
53	2,000	4.0	8.5	13,300	1,690	Almost fluid mud
25	1,600	25.0	3.0	22,400	19,750	Soft muddy bottoı
35	1,700	25.0	2.0	44,800	28,300	Mud 30′ deep
35	910	5.0	0.35	62,500	6,740	Mud, sand and cla
..	1,900	29.0	1.5	75,000	44,100	Stiff clay
91	2,300	22.0	1.75	75,000	36,800	Mud 60′. Sand 6′
73	2,300	33.5	3.75	34,000	32,500	Water 12′. Mud
30	2,300	22.0	2.0	38,000	33,700	Sand
33	2,300	22.0	1.0	110,000	50,600	Sand

[1] American Civil Engineer's Pocket Book, John Wiley & Son, Publish

In order to utilize the *Engineerings News* formulas with reason assurance of accuracy, the piles mut drive with fairly uniforr

ally increasing resistance; the hammer must not have a able rebound and must fall on solid uninjured pile top; that en test penetration is taken, broomed tops must be cut off e down to solid wood. *Also the formula for drop hammers es free fall. For a restrained fall where cable and drum remain ed to hammer use 80% of computed safe load as given by the la.* In driving test piles the safe load should be computed , 15′, 20′, etc. depths to determine the relation of length and



F. 346*A*.—Safe pile loads drop hammer test with free fall. r release.) Use 80% of safe loads for drop hammer with cable and drum rig.

ad in order to work out a reasonable length spacing layout dividual pile load. Piles are usually spaced 2½ to 3′, never an 2½′ and rarely over 4′. Tops should be cut off at stag- elevations to prevent a cleavage plane. Final top elevations ually 12 to 18″ above bottom of concrete.

P ctical refusal in driving piles is generally assumed when the nce to driving indicates the pile safe for 30 tons. This when the penetration per blow is from ⅛ to ⅕″ for ordinary hammers falling 15 to 20′ (see Figs. 346*A* and 346*B*). The drop hammer should weigh at least 2000 lbs. for timber piles he drop should not exceed 20 ft. In driving concrete piles the er should weigh at least as much as the pile and the drop

should not exceed 6 ft. In driving concrete piles steam ham striking a blow of at least 12,000 ft. lbs. are usually specified wit added requirement of water jets in hard driving. No effort sl be made to drive piles beyond the depth at which practical re is reached, unless pile penetration is less than minimum stipu and it is possible to get further penetration by water-jet met

Leads must be used even with double-acting steam hamme permit steam hammers to rest entire weight on top of pile.

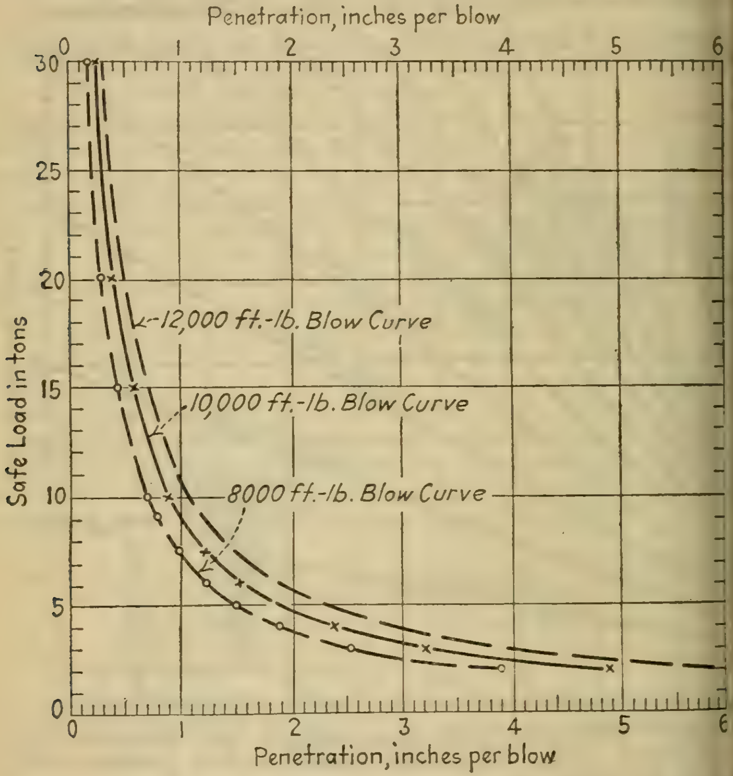


FIG. 346*B*.—Safe pile loads. Double acting steam hamme penetrations.

Engineering News Formulas

Drop hammers $P = \frac{2WH}{S + 1}$

Single-action steam hammers $P = \frac{2Wh}{S + 0.1}$

Double-action steam hammers $P = \frac{2E}{S + 0.1}$

P = safe load in pounds per pile.
W = weight of hammer in pounds.
h = fall of hammer in feet.
S = penetration per blow last 5 blows in inches.
E = energy of blow in feet, pounds. (Get from maker's catalog

TABLE 234.—TYPICAL DOUBLE-ACTING STEAM-HAMMER SIZES
Specifications of McKiernan-Terry pile hammers

Size of hammer	1	2	3	5	6	7	9-B-2	11-B
Net weight, pounds	145	343	675	1,500	2,900	5,000	6,760	13,185
Shipping weight, pounds	185	380	735	1,560	2,970	5,075	6,800	13,285
Cubic measurements, inches	9 × 11 × 47	11 × 10 × 37	14 × 13 × 62	19 × 14 × 57	24 × 19 × 63	27 × 21 × 73	24 × 20 × 92	30 × 26 × 110
Weight of ram, pounds	21	48	68	200	400	800	1,500	3,625
Bore, inches	2¼	4 1/16	3¼	7	9¾	12½	8½	12⅜
Stroke,[1] inches	3¾	5¼	5¾	7	8¾	9½	16	20
Strokes per minute	500	500	400	300	275	225	140	120
Foot-pounds energy per blow	100	140	350	1,000	2,500	4,150	8,200	22,080
Boiler horsepower required	10	10	15	20	25	35	40	60
Compressed air, actual cubic feet	75	85	90	200	275	350	400	600
Size of hose, inches	¾	¾	1	1¼	1¼	1½	1½	2
Size wood sheeting, square or round piling, inches	2 × 10	3 × 8	3 × 12	4 × 12	6 × 12	10 × 14	17	21
Penetration in average material, feet	4–6	6–10	6–10	10–15	15–20	20–30	30–40	60–80
Size steel sheet piling, inches	9	9	12	12	12	Largest	Largest	Largest
Penetration in average material, feet	6–10	10–15	10–15	15–20	20–30	30–40	50–60	70–100
Code word for hammer	GAFUP	GODME	IBALA	SOZBY	SUDDO	SUDOF	UBMIM	SUZEX

The strokes per minute given above should not be exceeded. See Table 234*A* for full details.

NOTE.—When ordering hammer sizes 9-B-2 or 11-B, be sure to specify whether flat or bell-bottom anvil block is wanted.

NOTE.—To get safe bearing power of piles for these hammers, use formula $L = \frac{2E}{S + 0.1}$ where

L = bearing power in pounds.
E = energy per blow in foot-pounds.
S = final penetration per blow in inches.

[1] NOTE.—For effect of variation in number of blows per minute on force of blow (E) see maker's catalogue. This is illustrated by Table 234*A* for McKiernan-Terry Hammers.

TABLE 234*A*

Size of hammer	Weight of ram, pounds	Lifting area of piston, square inches	Striking area of piston, square inches	Length of stroke, inches	Foot pounds l at given stro per minut	
					Strokes per minute	Fo pou p bl
No. 1	21	1.932	3.976	3¾	500	
No. 2	48	3.487	3.487	5¼	500	
No. 3	68	3.139	8.296	5¾	400	
No. 5	200	18.85	18.85	7	300 275 250	1
No. 6	400	36.18	36.18	8¾	275 230 200	[illegible]
No. 7	800	55.6	55.6	9½	225 195 170	[illegible]
No. 9-B-2	1,500	44.177	56.745	16	140 130 120	[illegible]
No. 11-B	3,625	100.645	120.28	20	120 110 100	2. 1[illegible] 1.

Attention is called to the fact that our hammers at the speeds ind above must develop the foot pounds per blow as specified. Calcul based on steam pressure are misleading because no two set-ups are ide and it is impossible to determine the mean effective pressure in the w cylinder from the boiler pressure as shown by gauge.

Figure 346*A* shows safe load 2000 lb. drop hammer for diff falls and penetrations with load factors for other hammer we *This diagram assumes free fall. For restrained fall (cable and attached to hammer) use 80% of loads given.*

Figure 346*B* shows safe loads for different penetrations per for double acting steam hammers striking a 10,000 ft. lb. with load factors for other forces of blow.

Table 234 gives typical double-acting steam-hammer spec tions.

As a check on the *Engineering News* formulas, Trautwine s that friction on piles will support following total loads per s of pile surface in contact with earth.

Soil	Total load per sq. ft. pile surface, pounds	Safe load pe ft. pile surf pounds
Dense moist sand................	2000	400
Loamy gravel....................	2000	400
Common soils and clays...........	1000 to 1500	200 to 30
Silt and mud....................	200 to 400	50 to 10

Horizontal Stability of Piles.—For the ordinary bridge foundation nditions there is rarely any doubt of horizontal stability but where es are driven through a very soft upper layer with only a short netration into an underlying hard layer and where after driving tops of the piles can be easily moved horizontally it is necessary insure against horizontal movement of the abutments by means batter piles. Where a condition of this kind is unexpectedly countered the inspector should get in touch with the bridge gineer for specific instructions as to the number, length, location d batter of the piles to be used to insure stability.

Inspectors Records.—Sample records for bridge work are given ow from the California Manual.

Forms.—The following figures illustrate typical forming for ncrete which is strong enough to prevent objectionable deflection.

The practice of the Illinois Highway Commission in designing ms for reinforced-concrete girder bridges is as follows:

"1. Rail and Girder Forms.—Forms for side rails of reinforced-concrete bridges may be constructed of 1″ sheeting with vertical studs placed not her apart than 2′. Forms for the girders of reinforced girder bridges uld preferably be constructed of commercial 2″ sheeting with studs not her apart than 2½′. All sheeting should be surfaced on the side adjacent he concrete.

"2. Bracing Rail Forms.—Rail or girder forms are best kept in line by ending the caps of each bent a sufficient distance, bracing them to the ework posts and then running a heavy stringpiece along the ends of the ended caps, bracing from this stringpiece to each stud of the rail or girder ns.

"3. Setting Panel and Coping Forms.—The panels and coping of rail girder forms should, whenever practicable, be omitted until the floor the span has been concreted. The weight of the floor is usually the ater part of the total weight of the superstructure, and if any settlement he falsework occurs, it is usually when the floor is placed. If the panel coping forms are completed before any concrete is placed, settlement of falsework will show in the panels and coping. It is not safe to trust to a nber to take care of the settlement, as the settlement is almost sure to be ven at the different supports. The side forms of the rails or girders uld preferably be left 3 or 4″ higher than the finished girder, and just ore the last concrete is placed, a triangular molding should be nailed on inside of the forms at the exact elevation required and used as a guide a template in striking off the top of the girder. If these precautions are en, the portions of the work visible from the roadway may show perfect s, although a settlement of the concrete may have occurred which shows sag in the bottom of the girders when viewed from the side. A small lement of falsework which occurs before the concrete has set does not re the strength of the bridge.

4. Construction of Girder Forms.—Girder forms should be so built as to mit of ready removal without injury to the concrete. The underside of ings should be given a pitch towards the girder for this purpose. Great should be taken to secure perfect alignment of rail and girder forms. al kinks should be taken out before the concrete is placed.

5. Alignment of Forms.—Correct alignment of girder and rail forms not be too strongly emphasized. Irregular lines are exceedingly unsightly as the bridge will be judged for all time to come from the appearance of portion visible from the roadway, if this appearance is unsightly, the lge will be condemned by the public regardless of the possible excellence he concrete."

The following instructions for constructing concrete highway lges forms were prepared by M. W. Torkelson, bridge engineer, sconsin Highway Commission.

1. Never place the bents for any kind of falsework more than 5′ apart.

2. If you can possibly get a pile driver, use driven piling to support your ework.

		STANDARD PILE RECOR			
	Specification Notes:				
Material Fir or Pine					
Load Required 20 Tons each					
Min. Tip 8″					
Min. Butt 20″					
Pay Length = Length below Cutoff					
Load = $P = \frac{2W.h}{S+1}$ where W = weight					
of hammer in lbs. S = Average Penetration					
in inches last 3 blows, h = height of drop					
in feet. P in pounds.					
	North Abutment				
No	Total Length	Cutoff	Pay L.	Last 3 blows Pen	h
1	24	4	20	1″	15
2	24	4	20	1½	15
3	25	5	20	2	15
4	26	6	20	1	15
5	23	3	20	2	15
6	22	2	20	2	15
Totals	144	24	120		
		South Abutment			
1	25	5	20	2	25

FIG. 347.—Sample construction pile records.

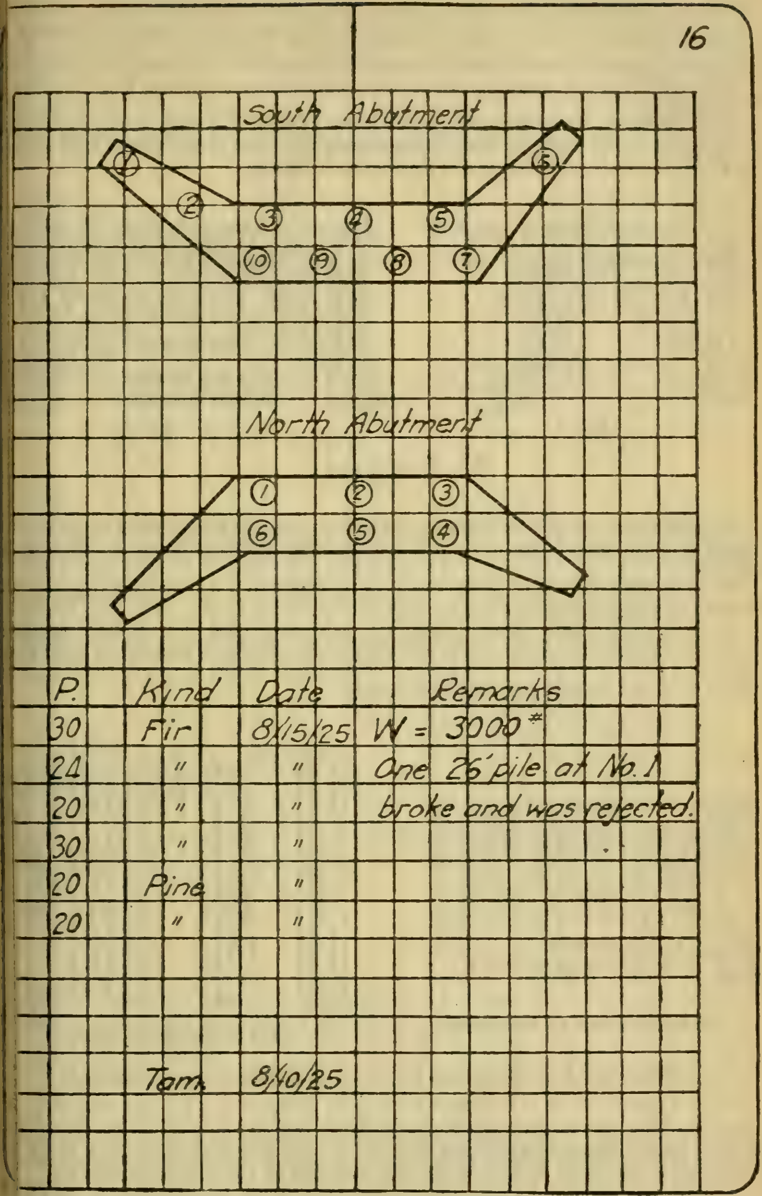


FIG. 347.—(*Continued.*)

"3. If you cannot get a pile driver, good bottom can be obtained by layi planks or timbers on the stream bed to get a good wide footing for each be then placing the mud sill upon the planks to support the posts. Before t planks or timbers are laid upon the stream bed, this should be leveled and soft mud or easily removed sand should be removed. Sometimes tempora concrete sills can be used to advantage, but the principle is the same as wooden sills.

"4. The posts for the bents should be 8″ thick and of good sound timb Always use eight posts in each bent where the road is 20′ wide, and arrar the posts so that two will come under each railing.

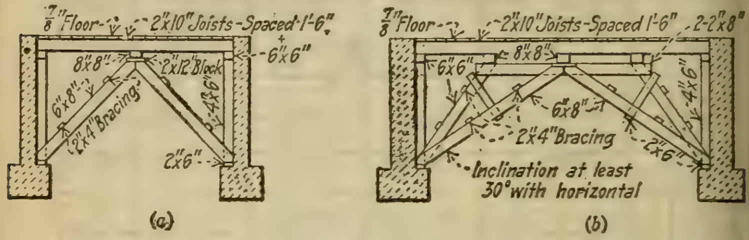


FIG. 348*A*.

"5. Use a heavy cap on top of the posts fastening either with dowels or means of very heavy spiking, and let this cap extend about 4′ beyond railing.

"6. The floor can best be directly supported by 2 by 10 joists spaced 1 Under railings double this up.

"7. With the joists spaced as in (6), the floor can be 1 or 7/8″ mater It should be nailed to the joists with 8-penny nails and should extend ab 4′ beyond the outside of the railing. This extra width is needed to brace railing and for walking across the bridge.

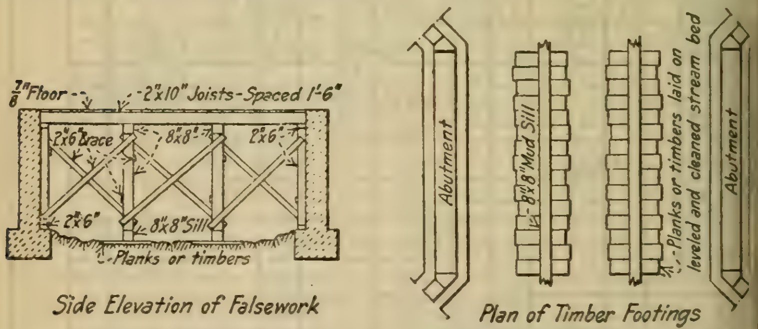


FIG. 348*B*.—Falsework for small concrete bridges.*

"8. Be sure to cross-brace the falsework both ways so that it will be l rigid against pressure from any direction. Unless this is looked after, falsework is likely to wobble when the placing of the concrete begins.

"9. Always use good planed and sized lumber on the railing, as this is part of the work which shows up. Have all panel work and three-corne chamfer strips made at the same planing mill. Send your bridge plan to mill and have strips cut to the proper dimensions. Wet railing fo thoroughly before pouring concrete.

"10. Always keep a man tamping the concrete next to the forms. will give a good smooth surface when they are removed and diminish work of finish. A wooden tamper will give better results than a steel sp

* NOTE.—Specifications mud sills, page 1521.

1. **Removal of Forms.**—In order to make possible the obtaining of a actory surface finish, forms, on ornamental work, railings, parapets, ertical surfaces that do not carry loads and that will be exposed in the ed work shall be removed in not less than 12 nor more than 48 hr., nding upon weather conditions. Forms under slabs, beams, girders, rches* shall remain in place at least 21 days in warm weather, and in weather at the discretion of the engineer. Forms shall always be ved from columns before removing shoring from beneath beams and s, in order to determine the conditions of column concrete.

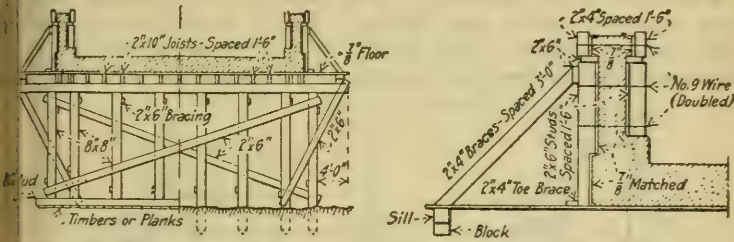


FIG. 349.

"o forms whatever shall be removed at any time without the consent engineer. Such consent shall not relieve the contractor of responsi- for the safety of the work. As soon as the forms are removed all places, holes, and porous spots shall be filled, and all bolts, wires, or appliances used to hold the forms and passing through the concrete be cut off or pushed back with nail set ½" below the surface and the overed with cement mortar of the same mix as used in the body of the ."

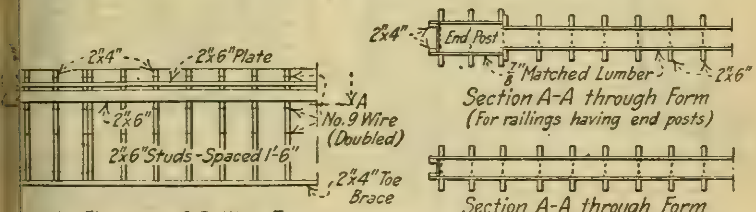


FIG. 350.

e falsework and form plans given in Figs. 348*A* to 350 were red by M. W. Torkelson, bridge engineer for the Wisconsin way Commission.

e plans shown in (*a*) Fig. 348*A* are for spans up to and includ- 4'; while the plans shown in (*b*) Fig. 348*A* are for spans of 16 inclusive. The bents should be spaced 5' centers. Use four 10" joists under the railing. Use hardwood wedges for cam- nd to facilitate removal of forms.

e falsework in Fig. 348*B* should be used where it is impossible ive piles. Bents should be spaced not more than 5' centers, wo posts should be spaced under the railing. Use four 2 by

*UTHOR'S NOTE.—A good rough and ready rule for minimum time in or removing forms under arches is to divide the span in feet by 4. ssumes warm weather. No backfill should be made in less than 28

10″ joists under the railing. Use 2 by 6″ joists on top of foc under each joist. Use hardwood wedges for camber and to fa tate erection. Details of an elevation of a bent are show Fig. 349.

The falsework bent shown in Fig. 349 may be a framed bent ported on a mudsill as is shown on the left, or may be a pile as shown on the right. Eight posts or eight piles should be in a bent for a 20′ roadway. Two posts or piles should be sp close together under the railing. Bents should be spaced more than 5′ centers. Use four 2 by 10″ joists under the ra Use hardwood wedges for camber and to facilitate erection.

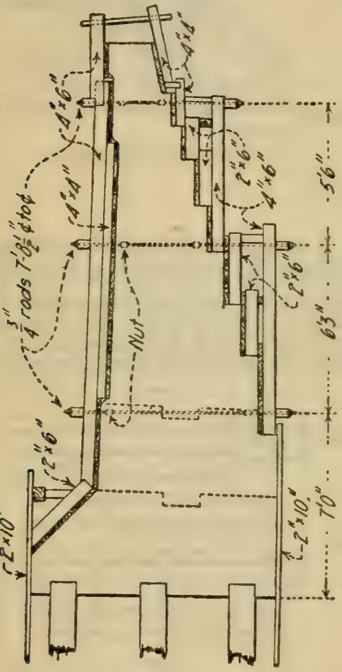


FIG. 351.

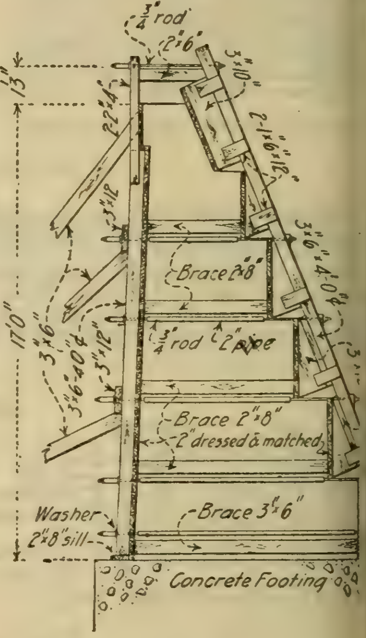


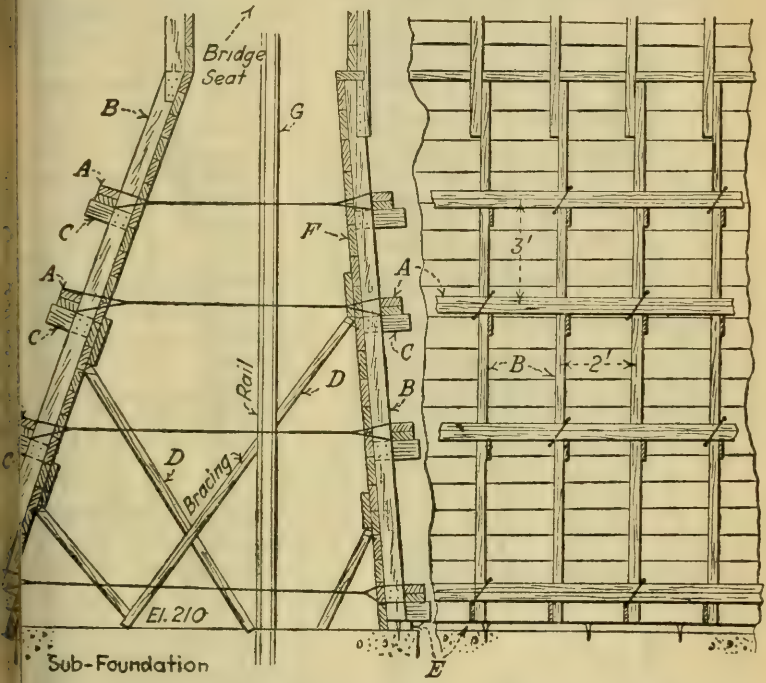
FIG. 352.

floor to top of curb, then build inside railing form to top of 6″ plate, or under side of coping, and pour rail to this point. concrete set while pouring other rail to this height. Return t rail and see if any settlement has occurred, and if so wed 2 by 6″ plate level before building form for coping. Always vide camber in forms ¼″ for each 10′ of span. Have t cornered strip made at planing mill. For elevation and se of railing forms, see Fig. 350.

Details of forms for retaining walls as constructed by the Il Central Railroad are shown in Fig. 351. The forms were structed in sections 54′ long. These forms were cross-brace ¾″ rods spaced 7′ 8½″ centers as shown. When the forms taken down, the ends of these roads were unscrewed, the

ons of the rod being left in the wall. The forms were made of ank surfaced on the inside.

rms used by the Chicago and Northwestern Railway are 1 in Fig. 352. The forms were built in sections 35′ long. The 8″ braces were used to hold the sides of the forms apart and removed as the concrete was put in place. The 2″ pipe used ver the rod bracing was old boiler flues and rejected pipe.

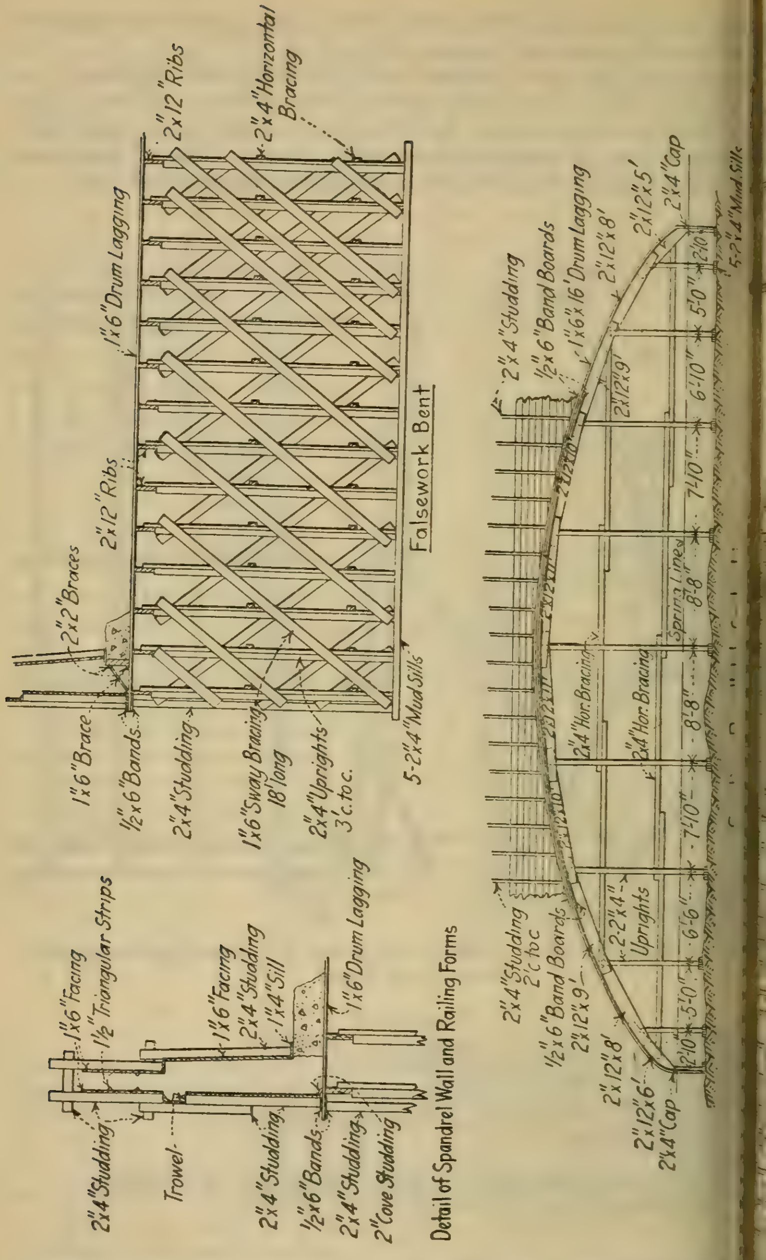


G. 53.—Typical form. High abutment Ry. elimination project. New York State.

Description

A. Whalers. Two 2 by 6″ boards nailed together.
B. Braces. 2 by 6″—spaced 2′ apart.
C. Braces to hold whaler in place.
D. Inside braces after forms were set. Notice pressure against wires.
E. This board held in place and form started from here.
F. Boarding 2 by 8″.
G. Rails.
W. is No. 9 form wire tied to whalers, twisted and also doubled.
Ws are staggered on different braces and whalers.

Typical abutment form New York State elimination abutment . 353.
Typical section arch form shown in Fig. 354.
Detail design data for forms given in Chap. XIV, page 1052.



Falsework Bent

Detail of Spandrel Wall and Railing Forms

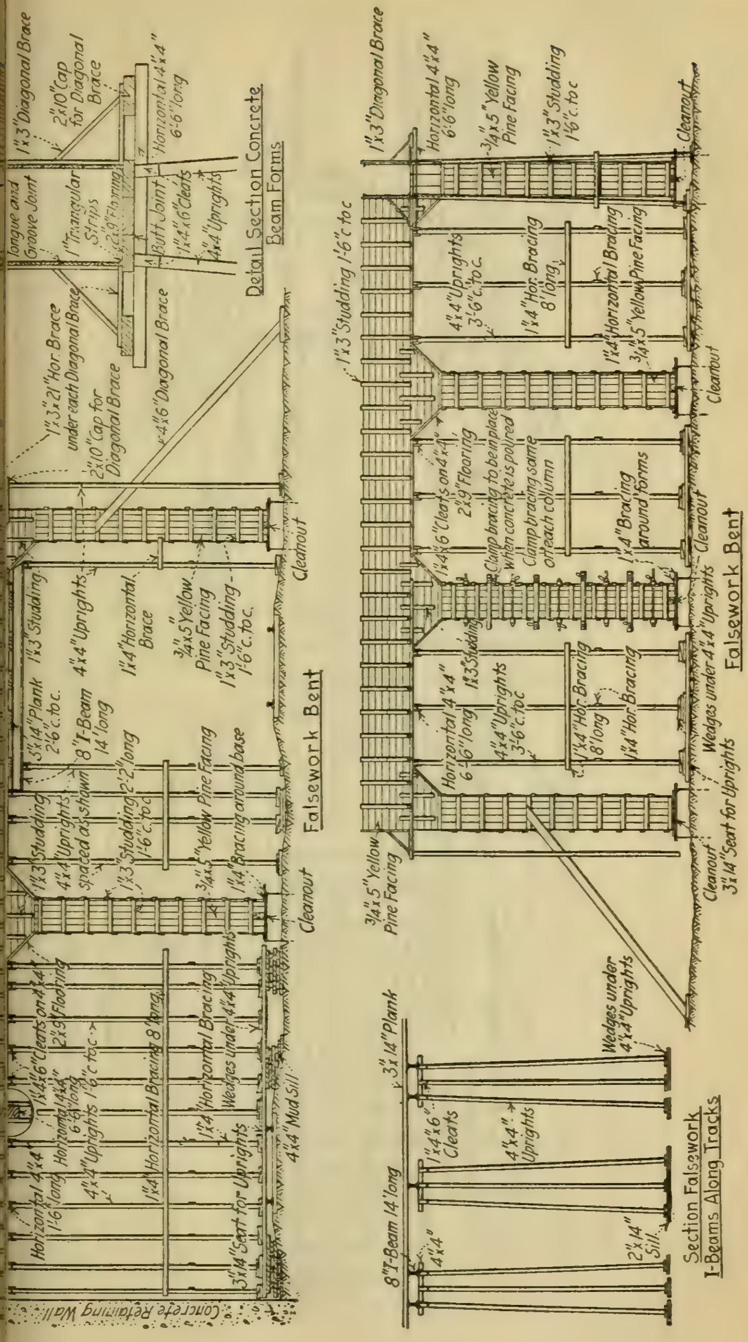


FIG. 354.—Typical trestle form.

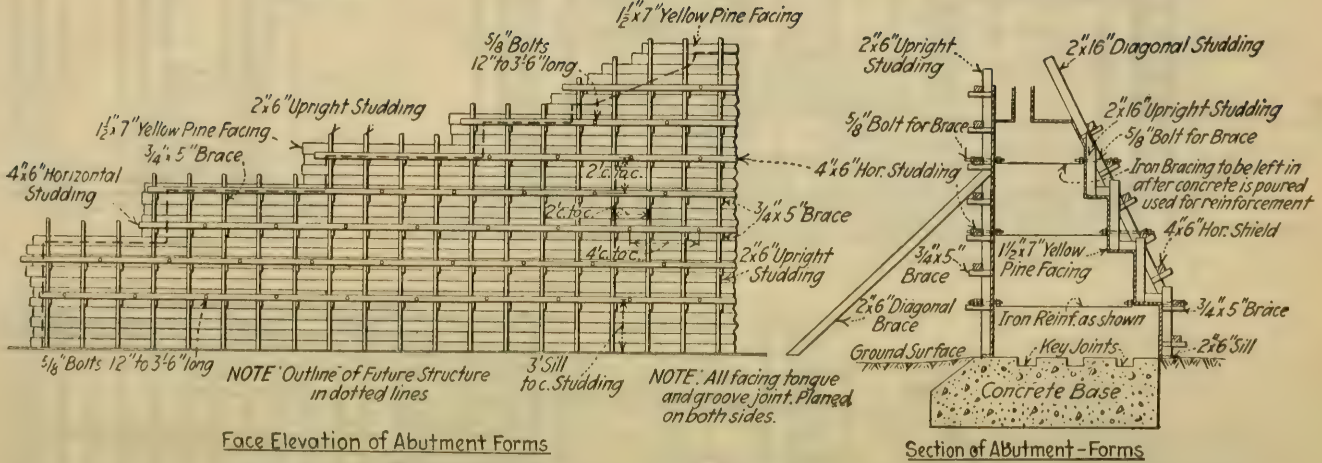


FIG. 354.—Typical abutment form. N. Y. Central railroad bridge.

NOTE.—If 1″ facing is used the vertical studding is spaced. 16″ c to c.

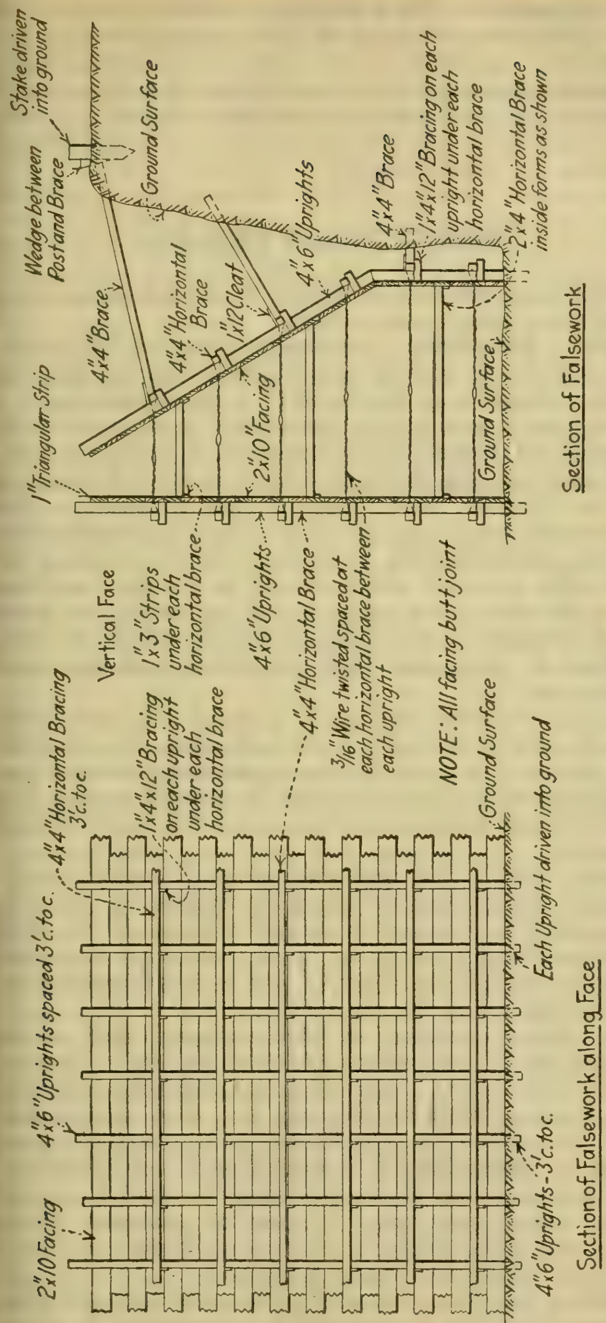


FIG. 354.—Typical high retaining wall form.

Bridge Inspection.—The following extracts from the Calif Highway Commission Manual of Instructions cover most p not specifically explained in the ordinary specification.] extracts are supplemented by a short statement in regard to fou tion soils, test piles, and staking out on pages 1334 to 1354, whic author has found to be convenient data for inspectors (see Specifications, pp. 1492 to 1572).

CONSTRUCTION DETAILS[1]

"Resident engineers shall be guided by the following instruc concerning the various types of work:

"**Section 1. Excavation.**—Safe and proper foundations for b structures are of the utmost importance. The life and safe the structure depends on the stability of its foundations.

"At the time a structure is designed, the type of footing the allowable soil pressures are determined from the most ava data, but upon opening the excavation pits the conditions m found to be different from those assumed in design. This make it desirable to alter the footings either by changing thei raising them, lowering them, by driving piles, or by other mea

"The bridge engineer shall always be notified sufficient advance of the date upon which it will be possible to inspec footings or foundation materials, so that he or his assistant inspect them to determine their suitability and pass upor desired changes.

"In case excavation is wet or the material is of such natur it has to be cribbed or shored, the cofferdam or crib shall sufficient size so that there will be ample room between the and the cofferdam to permit bracing, to provide pumps for p ing, and to permit inspection of the concrete after the forms been removed.

"The cofferdams, cribs, and shoring shall be sufficiently s to withstand the pressures caused by dewatering the pit. contractor shall be required to submit sketches of the meth constructing cofferdams or cribs. Braces shall not be permit extend into or through the concrete, but should be so arrange they can be removed as the concrete is placed.

"Before placing concrete, all loose material shall be ren from the bottom of excavations and from the walls where ex tion is made to neat lines. Care shall be taken not to allow ma which has been loosened by blasting, etc., to remain in footi abutment excavations (see specifications for details of excava

"**Section 2. Backfilling** (see specifications for details).— filling around piers and abutments shall be carried up unif around the entire structure. In case of approach fills a abutments, the filling shall not be done until the concrete h sufficiently to withstand the earth pressure.

"Backfilling that is to become an integral part of the roa embankment shall be compacted by spreading in thin

[1] California Manual.

rolled, tamped, puddled, or compacted by other methods approved by the bridge engineer. The class of material will determine the method to be used.

"No rubbish, timbers, or other foreign materials shall be used for backfilling. Boulders shall not be permitted to drop against the fresh concrete.

"Forms shall be removed to the ground line.

"**Section 3. Falsework.**—For important structures the contractor shall submit a plan for approval showing the proposed method of constructing the falsework (see specifications).

"Driven falsework is preferable, but framed falsework may be approved when soils are suitable, and when sufficient bearing is provided under the sills to prevent settlement. Especial care shall be taken to get sufficient bearing area in the case of adobe or clay soils because of the liability of the soil becoming wet and soft when concrete is placed. Falsework shall be so constructed that in the event of settlement it can be taken up with wedges. In case of supports being placed where excavation has been made, the supporting timbers shall be set upon the original firm ground or where possible upon the concrete footings.

"It shall be constructed with braces and fastened together in such a manner as to act as a unit so that the settlement will be practically uniform.

"The use of bolts in fastening falsework is preferable to spiking, as it will be much more rigid and removal will be facilitated.

"Plans for arch centering, trussed falsework, and falsework for structures over railway tracks must be submitted to the bridge engineer for approval before their use will be permitted. In the case of supports over railway tracks, it is necessary that the plans be approved by the railway officials. The resident engineer will see that these plans are submitted sufficiently in advance of their use, so that there will be ample time for approval.

"In setting grades for falsework, an allowance shall be made not only for settlement occurring from the soil, but for closing of horizontal joints in vertical framing. This allowance shall be determined as far as possible by data obtained from previous work. The resident engineer shall take careful levels before and after placing of concrete, and before removal of forms, submitting the settlement data so obtained together with a sketch of the falsework used, and a description of conditions, in the final report of the work.

"**Section 4. Forms.**—The plan submitted by the contractor for the falsework shall include the forming plan.

"In constructing forms, the grade, alignment, surface appearance, and rigidity shall always be kept in mind.

"Forms shall be constructed of lumber surfaced one side and two edges. Joints in sheeting shall be permitted only at studs. Studs shall be spaced so that the lines will be straight and true, with no bulging and tipping out of line. Where 1″ lumber is used for sheeting, studs shall be held by means of walings of sufficient size to insure rigidity of the forms. The use of 2″ T and G lumber on the exposed surfaces will give a much better finished appearance and will facilitate finishing the concrete surface.

"If green lumber is used, the sheeting shall be nailed as tight a possible. If thoroughly seasoned lumber is used, the forms sha be oiled before the concrete is placed, or a space from 1/16 to 1/8 in width, depending upon the condition of the lumber, shall l left to take care of swell. These cracks shall be closed t thoroughly soaking the forms with water prior to placing concret in order to prevent loss of cement and an unsightly surface finis Ship-lap may by used but it shall be thoroughly seasoned prevent shrinkage of the forms.

"Knot holes and other apertures in forms shall be closed in a acceptable manner before placing the concrete. Sheeting of width greater than 8″ will not be permitted unless special pr cautions are taken to prevent warping.

"The amount of camber to be used in placing falsework depen upon the bearing power of the soil, type of forms, number of joir in the falsework and length of span. The camber shown on t plans is the amount that should exist after the forms have be removed. A reasonably safe rule to follow is to double this amou to allow the settlement, but local conditions must be considered determining this amount. The thickness of the floor slab sh be the same at all points regardless of the amount of camber use

"The use of bolts as tie rods in forms where practicable, such a piers, abutments, or other mass concrete, is desirable because the rigidity obtained. When wire is used, it shall be of sufficie strength and elasticity to permit thorough tightening.

"Oiled or other treated forms are desirable, but oiling must done before the reinforcing steel is placed.

"If steel forms are used, they must be made of metal of sufficie gage to withstand knocks, so as not to become dented. If of la size they shall be constructed with stiffeners to prevent bendi When reused they must be thoroughly cleaned and oiled bef concrete shall again be placed against them.

"If railing forms are constructed of lumber, the best results v be obtained by using tongue and groove flooring for sheeting a other lumber cut to size with a minimum of joints and trea with white shellac. Bolts are preferable, as wired forms are flexible and difficult to tighten in the thin section. The rail forms shall be set true to line and grade by using transit and le

"Section 5. Reinforcing Steel.—The placing of the reinfor ment is a very important detail of the concrete structure. T success of the structure depends upon the reinforced membe The resident engineer shall see that the steel is furnished accordin specifications, that none is placed unless absolutely clean, that spacing in all cases is correct, that all bars are tied at intersecti (with figure-eight ties), adequately supported by concrete blo or other acceptable means and that there is sufficient sp between the steel and surface of concrete to give full protection the steel.

"Laps are to be made only where shown on the plans unl authorized by the bridge engineer or his assistant and when ma shall be not less than 40 diameters. At laps the steel shall be located that there will be at least 2″ of concrete around each ba

"Extreme care shall be exercised during placing of concrete to see t the steel does not become misplaced. The bars should be gled to insure a good bond.

"If for any reason concrete becomes dried on the bars before they covered, it shall be removed by scraping and not by hammering bars.

"**Section 6. Concrete.** (*a*) *Mixing* (see specifications and n 7 on page 39 of the Construction Department Manual).—en starting the placement of concrete the rock may be reduced the first few batches until the mixer has become thoroughly ted with cement in order to insure the workability of the crete.

(*b*) *Placing* (see specifications).—It is of the utmost importance t concrete be properly placed and, in order to secure the required ılts, the resident engineers must give this close and minute ention.

The plans will contain a diagram showing the successive locas of concrete placement. The contractor shall equip the work uch a way that this can be followed. If it is necessary to make ts in the concrete, they shall be horizontal in piers and abutıts, except in abutments for arch spans when they shall be le at right angles to the resultant line of thrusts. If joints are le, they shall be securely bonded by stepping, notching or by of dowels or other acceptable means. Joints will not be perted in girder spans except as shown on the plans, unless author- by the bridge engineer (see plates 355 and 356).

CONSTRUCTION JOINTS

Iass Concrete.—Construction joints in mass concrete abutıts, wings and walls are often necessary and there is no objection their use. The concrete is brought up in horizontal layers o 8″ thick to permit proper placing and spading. At the end of days' work a key or dowel joint is provided. Dowel joints by ns of vertical steel beams or rails as shown in Fig. 353 are the t convenient method and are usually adopted utilizing old steel ı the old bridge but key joints similar to Fig. 354, page 1352, are rely satisfactory. These key joints should be approximately o 12″ deep and have a top area of approximately 30% of the l area to be bonded.

lab decks should be constructed full depth for the entire span ne operation and if there is any doubt of being able to accomı this they should be laid in strips parallel to the span and each completed. There is no objection to laying in a series of s. If a breakdown makes it necessary to stop work and it is ssible to finish by hand mixing methods put in a header perlicular to the axis of the slab and provide corrugated key ections of at least 30% of the section area as shown in Fig. 356. se joints should be located at points of least shear (near center an).

rch rings are handled in the same manner as slabs except that is started at both abutments working towards the crown to

keep a symmetrical load on the center and prevent distortion. It common practice to lay arch rings in strips but intermediate joir

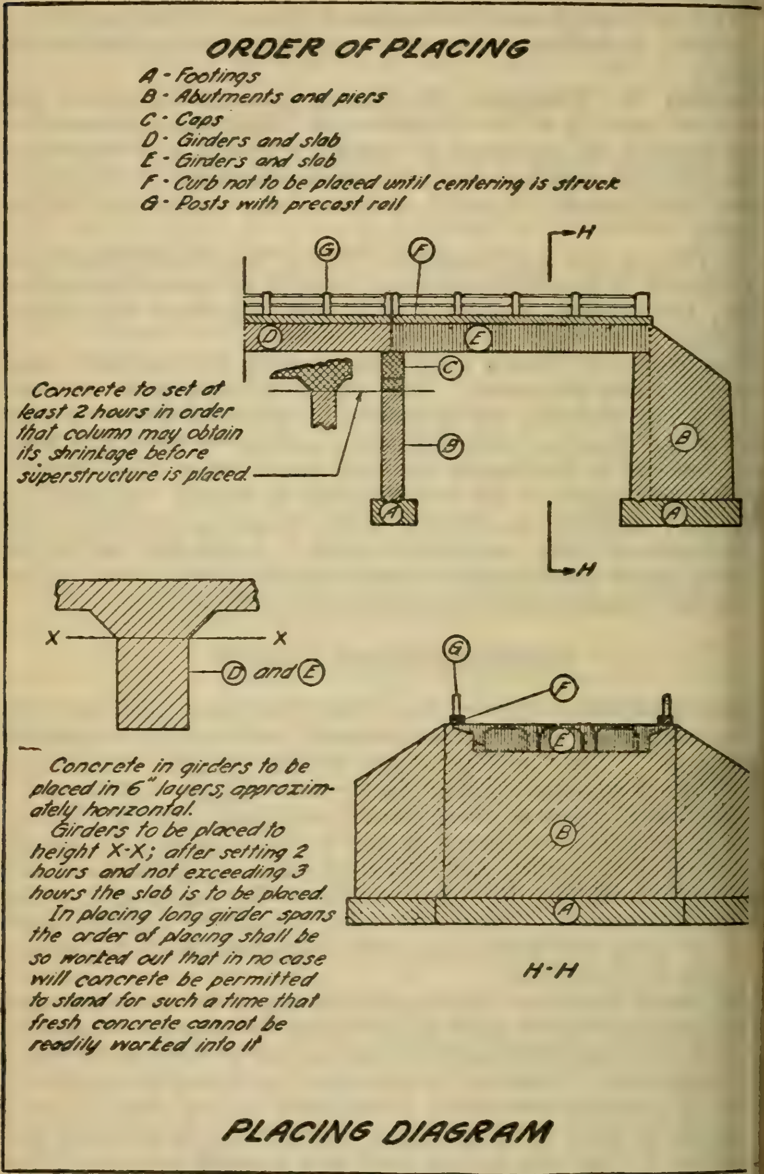


FIG. 355.—Order of placing concrete.

are to be avoided if possible; when necessary they should be perp dicular to the arch ring radius and can be placed at any loca without much danger of weakness.

irders are handled in the same manner as slabs except that they t not be constructed in strips.

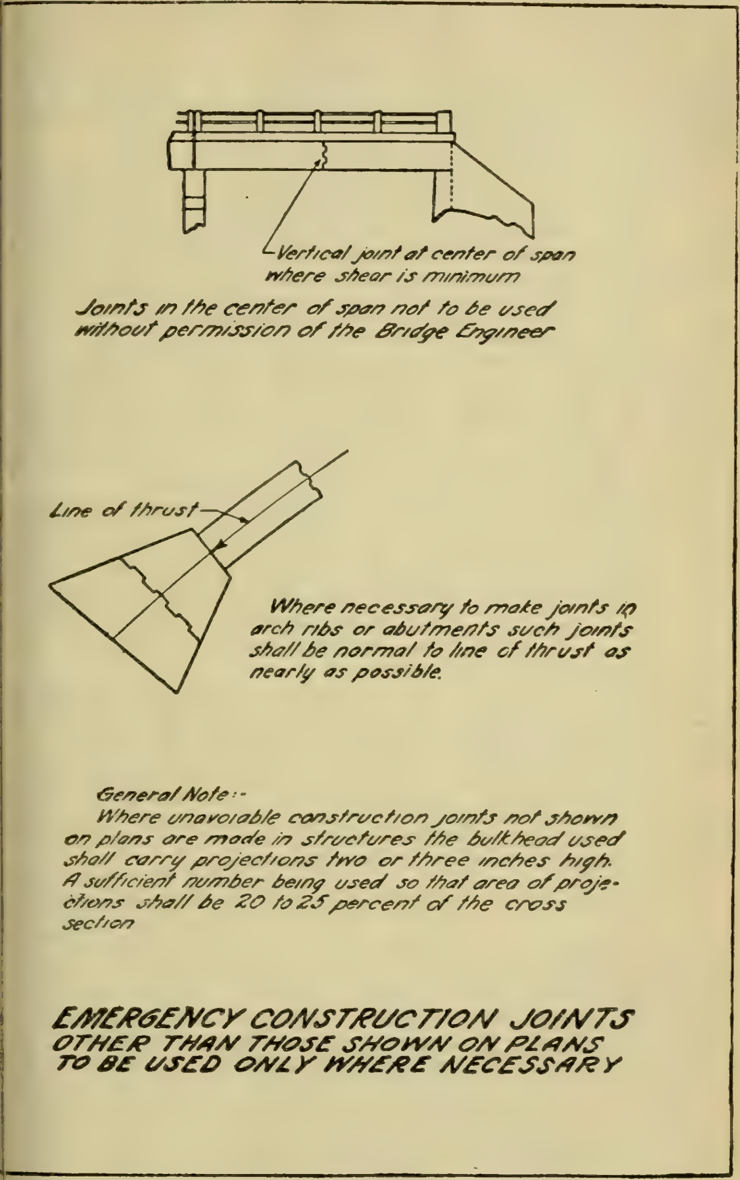


FIG. 356.—Emergency construction joints.

beams are the most difficult deck to pour properly and a strong should be made to complete the superstructure in one con-

tinuous pour even if double shifts are required. The inspe should have in mind that for T-beam construction, Fig. 73, page the floor slab is part of the beam and concrete must be poured depth, both beam and slab being carried forward in one operat The best method of pouring a T-beam structure is to start at side of the bridge, pour one beam and slab complete and then w across the bridge completing each beam and slab one at a ti In case a break down forces a joint the best location is in the f slab parallel and midway between two beams.

"Concrete shall not be placed in the curb and railing until falsework has been removed, except in the case of through gi spans when the girder and curb shall be placed monolithic The curb and railing shall be constructed separately. The utr care shall be exercised to keep the forms in good alignment.

"Except in cases of necessity, no concrete shall be placed ui water and at no time will it be permissible to place concret running water. When concrete is placed under water, it shal by means of a tremie, bottom-dump bucket or other met equally as good, and acceptable to the bridge engineer. concrete shall be of such consistency that it will flow and separate when deposited under the water; if it is too dry or wet it will separate with a resulting poor concrete.

"Concrete shall be placed in successive layers in all portioi the work except the deck. As each layer is placed, it shal thoroughly rodded and worked into a compact mass. In forms care shall be exercised to see that the placing is not so r as to permit sufficient pressure to accumulate as to cause bul of the forms. Care shall be exercised to see that all bolts or are tight at all times.

"In piers, abutments, or other large masses the concrete ca spaded very satisfactorily with a square-point shovel, but in sm sections it will be necessary to have special tools.

"When boulders (plum rocks) are placed in mass concrete, shall be placed in such a manner as to insure their being thorou imbedded with no air pockets around them and not less tha of concrete on all sides (see specifications).

"When placing concrete in girders or beams, the first layer be just sufficient to cover the steel and shall start at one end be carried continuously along the full length of the girders b the second layer is started. The succeeding layers shall t proper thickness to permit proper working of the concrete. V placing of concrete is in progress and before it has taken the ir set, the forms shall be hammered on the outside with a wo mallet or hammer to insure the mortar being brought to the sur

"When placing concrete in the deck, it shall be started at one brought up to grade, and carried forward in one operation. surface and grade shall be obtained either by using screeds s grade or by means of a template cut to the proper crown operated on the side forms. The surface shall then be smoo longitudinally with a wooden float, operated with a comb longitudinal and transverse motion to plane off the high places bring the low places up to grade. After this has been accomplis

mooth surface shall be obtained by finishing with a belt, hose, t or other acceptable method. It is essential that a smooth-ing surface be obtained so that impact will be reduced to a imum.

Where angle irons are placed at points, extreme care shall be rcised to see that they fit true to grade, are not tipped, and are urely fastened before the placement of concrete is commenced. ring the placing of concrete they shall be carefully watched to that they are not knocked out of position. It is preferable to e angles $\frac{1}{8}''$ below grade.

The placing of concrete in the curbs and railing shall be carried n layers, and after a layer has been spaded and worked suffici-y, it shall not be disturbed in spading the succeeding layers, in doing so air pockets will be formed on the surface with a lting poor finish.

(c) *Finishing* (see specifications).—A good finished appearance sential at all times. Good finish depends upon good formwork, in placing, removal of forms as soon as possible, and care in hing by experienced labor.

At all corners where possible, such as at construction joints and tops of forms, an edging tool of proper radius shall be used to d the corners. Corners that cannot be treated in this manner l be chamfered, either by nailing a fillet of the required dimen-s, to the forms, or by beveling the corners of the forms.

Excellent results will be obtained by finishing in two operations, ely, "first rub" and "second rub."

The "first rub" is a surface treatment of imperfections that are ent upon removal of forms, such as form marks, bolt holes, ruding tie wires, etc., and must be made immediately upon oval of forms—usually done within 24 to 48 hr. after concrete aced, on vertical surfaces that are not supporting members. A tar composed of 1 part cement to 3 parts sand (screened ugh a 14- or 16-mesh screen) is applied to the entire surface, r removing any fins or projections, while the concrete is green hat it will become an integral part of the surface. Care shall exercised that the mixture is not too rich so that checking of the ace will be prevented.

The "second rub" can best be done as the last operation when ther work on the structure is completed, the workman to start e top and work down, the treatment to consist of the applica-of water and very thorough rubbing with carborundum stones. The quality of the finish obtained depends upon the skill of the men, as in both "first" and "second" rub, hard work, proper rvision, and particular care must be exercised to leave the ce without showing lines where work started and stopped.

Mechanical means of surfacing may be employed if the results ined are of the same quality as the foregoing.

If dark cement is used in the railings, a small amount of hydrated should be added to the mixture to make a lighter color in this on of the structure.

(d) *Curing* (see specifications).—Where possible the curing of rete shall be done by covering the surface with earth and

dyking or flooding with water. In places where this metho not possible, the concrete shall be kept wet by sprinkling or cove with burlap that is kept well dampened the required length of ti The resident engineer shall insist upon proper curing. The stren of structures will be greatly affected by the curing and may reduced as much as 30% if this work is not properly done. W this in view steps shall be taken to cure the concrete as soor possible after it is in place.

"**Section 7. Waterproofing and Repair of Concrete Structu** (*a*) *Necessity for Waterproofing.*—Where structures are subje to action from salt air and salt water or alkali, it is important t the concrete be as impervious as possible. If there is any poros the salt water and alkali will attack the concrete, and if ther steel within reach, it will corrode. When steel corrodes, it expa destroying the bond and cracking the covering concrete.

"(*b*) *Waterproofing New Structures.*—The best method of prev ing this destructive action is by obtaining a dense concrete w the structure is constructed. In order to obtain a dense conc the utmost care and attention must be exercised.

"There are certain rules and practice to be followed as given be

1. Use of dense, rich concrete, not less than 6 sacks of cement per cu
2. From 2′ below low water to 2′ above high water 7 sacks of cemen cu. yd. shall preferably be used.
3. Concrete to be deposited in dry when possible.
4. Avoid contact of salt water with the concrete for at least 4 days placing (see p. 1530).
5. Use of strong, sound aggregates.
6. Avoidance of beach sands.
7. Fresh water to be used in mixing concrete. A minimum of water used at all times.
8. Only concrete block chairs to be used for supporting reinforcing
9. Reinforcing steel to be well imbedded in the concrete.
10. Construction joints to be reduced to a minimum number.
11. Concrete to be spaded and tamped thoroughly to produce a uni skin surface.
12. Oiled or treated forms.
13. Concrete to be mixed not less than 2 min.

"(*c*) *Repairing Old Structures.*—The best method of repairi reinforced-concrete structure that has been affected by the a of salt water or alkali is to remove loose concrete and recove reinforcing steel with concrete. Small repairs can be mad hand methods but where any quantity of repairing is to be done of the best methods is to apply gunnite.

"**Section 8. Pile Driving.** (*a*) *Materials.*—For details materials for all classes of piling, see specifications.

"(*b*) *Limitation of Use.*—In general, the penetration for pile shall be not less than 10′ in hard material and not less one-third the length of the pile nor less than 20′ in soft materi

"For foundation work, no piling shall be used to penetrate a soft upper stratum overlying a hard stratum unless the penetrate the hard material a sufficient distance rigidly to fix ends.

"(*c*) *Caps.*—The heads of all concrete piles, and the hea timber piles when the nature of the driving is such as undul injure them, shall be protected by caps of approved design, pr

having a rope or other suitable cushion next to the pile head fitting into a casting which in turn supports a timber shock k. When the area of the head of any timber pile is greater that of the face of the hammer, a suitable cap shall be prod to distribute the blow of the hammer throughout the cross-

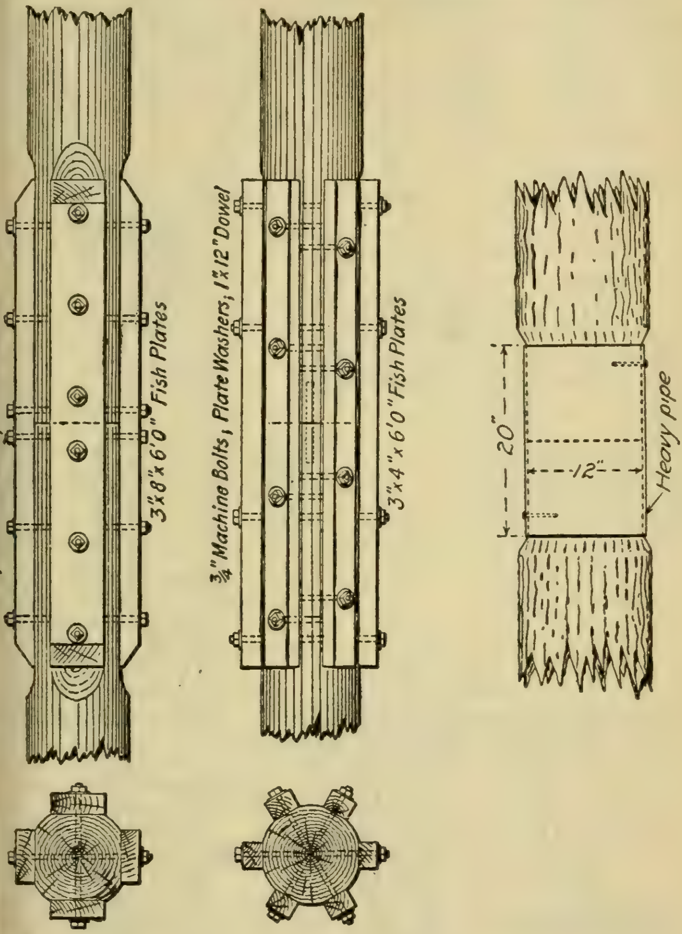


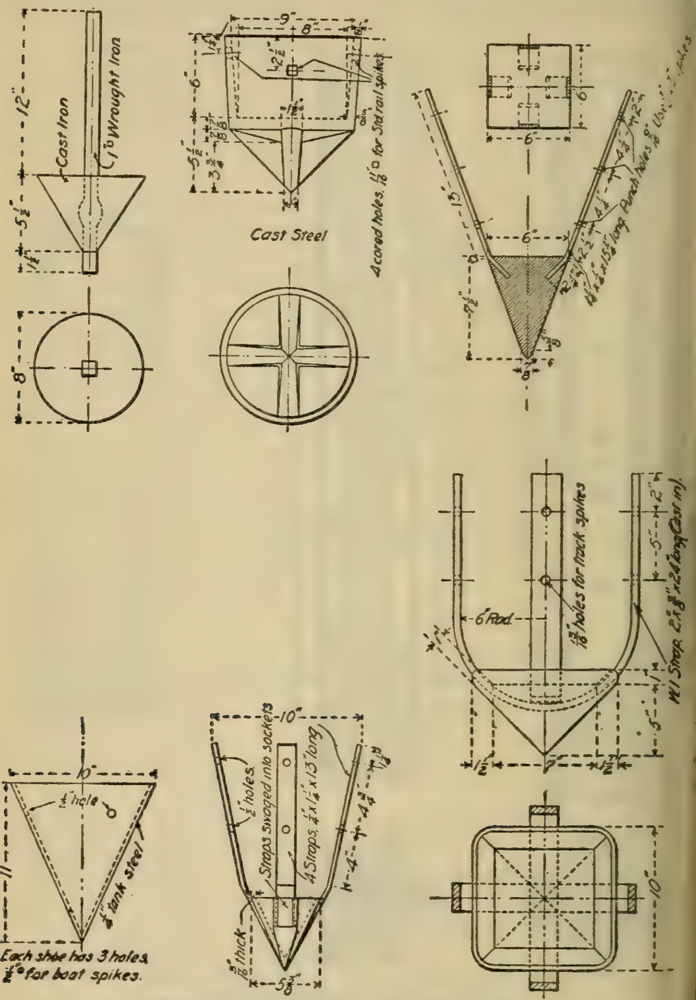
FIG. 357.—Pile splices.

on of the pile and thus avoid, as far as possible, the tendency lit or shatter the pile.

) *Splicing Timber Piles.*—Piles shall not be spliced except by ermission of the bridge engineer.

) *Methods of Driving.*—Timber piles shall be driven with a drop mer, steam hammer, water jets, or a combination of water jet hammer. Concrete piles shall not be driven without the ination of steam hammer and jet except by permission of the e engineer. Two jets shall preferably be used to eliminate

the possibility of the pile crawling. If satisfactory to the bri engineer, concrete piles may be used, cast with a pipe through center. The final penetration shall be secured without the ai the jet.



FIGS. 13*d*, *e* and *f*.—Shoes for Timber Piles.

FIG. 358.—Pile shoes.

"When gravity hammers are used, they shall weigh not less 3000 lb. and the fall shall be so regulated as to avoid injury t pile and in no case shall exceed 15′.

"When the penetration is ⅛″ or less per blow, driving sha stopped, as such penetration shall be considered refusal

"Steam hammers shall develop an energy per blow of not less 12,000 ft.-lb.

The leads shall be so guyed or braced as to hold the pile in posi- i during the entire process of driving. Extension leads are erred, but the use of a follower will be permitted when neces- a. A submarine hammer may be used where piles are driven er water, but they must be of such length that when cut off e will be a sound, clean head.

There shall be a variation of not more than ¼″ per foot from the ical or batter line indicated.

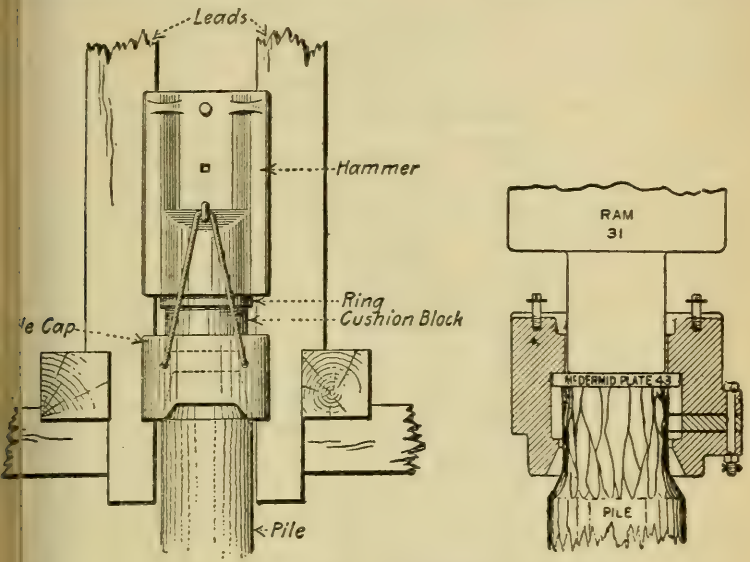


FIG. 359.—Pile caps.

n some instances loading tests may be necessary to determine bearing value of piles. More generally, however, the following ulas shall be used to determine bearing values:

$$P = \frac{2WH}{s + 1.0} \text{ for drop hammers}$$

$$P = \frac{2WH}{s + 0.1} \text{ for single-acting steam hammers}$$

$$P^1 = \frac{2H(W + Ap)}{s + 0.1} \text{ for double-acting steam hammers}$$

e P = safe bearing power in pounds.
W = weight in pounds of striking parts of hammer
H = height of fall in feet or length of stroke.
A = area of piston in square inches.
p = steam pressure in pounds per square inch.
s = The average penetration in inches per blow for the last 5 to 10 blows for gravity hammers and the last 10 to 20 blows for steam hammers.

[1] UTHOR'S NOTE.—Formula page 1340 using maker's speed of blow in deter- g E is more reliable than the use of steam pressure area and stroke.

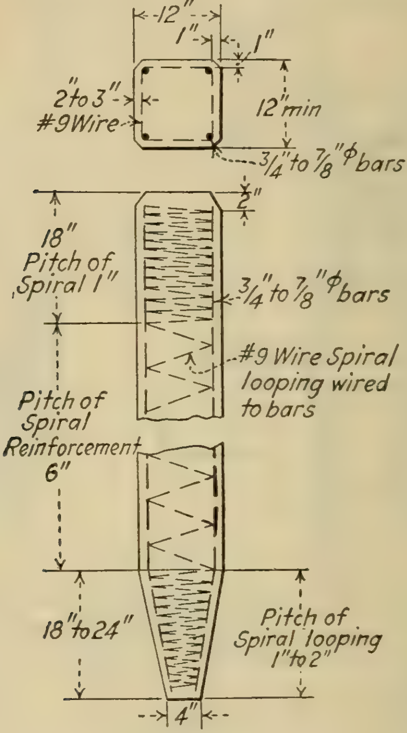
"The above formulas are applicable only when

"*a.* The hammer has a free fall.

"*b.* The head of the pile is free from broomed or crushed w
fiber.

"*c.* The penetration is at a reasonably quick and uniform rat

"*d.* There is no perceptible bounce after the blow. Twice
height of the bounce shall be deducted from *H* to determine
true value in the formula.



Typical precast concrete pile
Ordinary strength up to 30′.

"In case water jets are used in connection with the driving
bearing power shall be determined by the above formulas from
results of driving after the jets have been withdrawn, or a load
may be applied.

"When required, by the bridge engineer, test piles shall be dr
of a length and at the location designated. These piles shall l
greater length than the length assumed in the design in orde
provide for any variation in soil conditions.

"After proper penetration is determined by driving test p
the resident engineer shall furnish the contractor with an item
list showing the number and length of all piles, and the contra
shall furnish piles in accordance with such itemized list.

The storage of piles in all cases shall be such as to avoid injury to the pile. If the surface of treated piles is bruised, it shall be treated in an acceptable manner.

The tops of all piling shall be sawed to a true plane as shown on the plans and at the elevation so indicated. Piles which support timber caps or grillage work shall be sawed to the exact plane of the superimposed structure and shall exactly fit it. Foundation piles shall be cut off at staggered elevations so that cleavage planes shall be avoided. Broken, split or misplaced piles shall be withdrawn and properly replaced. Also, those driven below cut-off grade and by the engineer shall be withdrawn and replaced by new and if necessary, longer piles at the expense of the contractor. All piles raised during the process of driving the adjacent piles shall be driven down again.

(f) *Concrete Piles.*[1]—In general the same rules that apply to other concrete shall govern the mixing and placing of precast concrete piles. The casting platform shall be so constructed that it is absolutely level and so there shall be no settlement when the load of concrete is applied.

The forms shall be of the same standard as required for other classes of concrete work and of sufficient stability to prevent warping, tipping out of line, or bending. They shall be so constructed that removal can be made within 48 hr. without moving the pile. As soon as the forms are removed, the surface shall be treated in the same manner as specified for other concrete surface treatment. They shall also be cured in the same manner. They shall not be moved until the 28 days have elapsed and in case of piles to be driven in salt water preferably not before 60 days.

In handling piles, care shall be taken not to bruise the surface or break the corners. Piles shall be handled by means of a sling or other acceptable method to prevent undue stresses with resulting fracture of the pile. If they are cracked or damaged in handling so as to be unfit for use, it will be cause for rejection and all such piles shall be replaced by the contractor at his expense.

It is preferred that piles be cast full length of the reinforcement and cut off to the required height, but if this is not done, the contractor shall protect the projecting steel during driving.

The reinforcing steel shall have a cover of not less than 2″ and where piles are subject to the action of salt air and water a minimum cover of 3″ shall be obtained.

In driving piles for concrete bents, a good method to follow is first to drive the vertical piles and to provide a guide for the batter piles by bolting two large timbers alongside the vertical piles. This will help to keep all the piles in line.

(g) *Sheet Piling.*—These rules apply only to such sheet piling as may be specified in the contract and not to methods which the contractor may employ in the prosecution of the work.

[1] Author's Note.—Figure of typical concrete pile based on 1% to 1½% longitudinal reinforcement with looping as shown. This pile is a safe design for up to 30 ton load up to about 30 ft. total length. For special heavy loads and extreme lengths see Jacoby and Davis Foundations for Design of Precast Piles

"The type and quality of piles used shall be as specified and sh be driven to the required elevation.

"They shall be driven in approximately the same manner specified for other piles but shall be drift sharpened so that adjac piles shall be wedged tightly together. They shall be bra securely by means of waling strips either on the inside or on outside as conditions require. The wales shall be of one len where possible. If splices are necessary they shall be made w timber of the same section as the wale itself and securely bolt The sheet piles shall be bolted to the wales sufficiently to g stability.

STEEL STRUCTURES[1]

"Section 1. Shop Inspection.—All important steel structu are usually inspected at the shops, but whether shop inspect has been made or not, work which does not conform to the spec cations and to recognized good practice shall be rejected by resident engineer.

"Section 2. Unloading and Storage.—When the steel arrive the site of the work, the resident engineer shall see that i unloaded in such a way as to avoid bending of plates or member unduly marring the shop paint. The steel shall be placed i protected place upon a substantial raised platform. It shal piled in such a way that it will not topple over or the steel be b by an excess weight upon it.

"Any material bent in shipping shall be straightened cold. it is so badly bent that this cannot be done, it shall be rejec

"Section 3. Falsework.—Before any steel is erected, the fa work shall be carefully inspected by the resident engineer. shall see that camber blocks are set to the proper grades alignment and that they are maintained until the span is swun

"Section 4. Anchor Bolts.—The resident engineer shall see t the anchor-bolt holes are drilled in the correct location and pendicular to the plane of the bridge seat. Great care shall exercised to see that anchor bolts are set in exact position securely grouted into place. Expansion ends of trusses must free to move longitudinally under change of temperature but t should be anchored against lifting or moving sidewise. To acc plish this, the nuts on the anchor bolts should be brought dow allow a slight clearance between the nut and the shoe. Maso plates should be grouted in such a manner as to insure per bearing over the entire surface of the plate and they must be l and to exact elevation.

"Section 5. Erection.—Segmental rollers should be set to exact angle shown on the plans. When the span is swung and floor is completed, the rollers will stand vertical at the aver temperature. If the angle of inclination is not shown, the atten of the bridge engineer should be called to the fact. In assemb steel, the resident engineer shall see that proper care is observe avoid injury or damage to the various parts. Excessive hamme

[1] See also pp. 1533 to 1566.

h may distort the metal shall not be permitted. All parts be placed in accordance with the erection diagram of ing drawings. Reamed connections which have been match ed in the shop should be erected in accordance with those s.

Drifting which would distort the metal shall not be permitted. ld holes be poorly matched, they should be reamed to such as will give a true hole throughout and larger rivets driven. l cases, the resident engineer shall see that the proper sequence bserved in riveting in order that all rivets may be driven. re permitting riveting, all members shall be accurately and y bolted up and all burred edges should be removed so that arts are in close contact. At least 25% of the holes shall be d.

The resident engineer shall check the sizes of all members, see all joints, shown on the plans as milled, are brought to perfect ng, that all loose fillers and pin packing or ring fillers are d as shown.

ection 6. Riveting.—All field riveting shall be done with matic hammers. The resident engineer shall check rivets length as per standard specifications. Rivets shall be heated rmly to a light cherry-red color and be at that color when ted in the holes for driving. The heating of the points of s more than the remainder shall not be permitted. When y for driving they should be free from slag, scale, and other ring matter and when driven they should completely fill the . Burned, burred or otherwise defective rivets and rivets h throw off sparks when taken from the forge shall not be n. Rivets whose heads are pitted from burning shall be ted.

There have been times when as many as 25% of rivets that have placed on the job have had to be removed. To prevent this, esident engineer shall inform the contractor in advance that such riveting as is of the best quality and workmanship will ccepted and that other than perfect rivets will have to be ved and replaced. No recupping or calking will be allowed. e, burned, badly formed or otherwise defective rivets shall be ut. All rivets shall be required to have full heads and line ith rows in which they are driven.

n cutting out defective rivets, care shall be taken not to injure djacent metal and if necessary the resident engineer shall re the rivet shanks to be removed by drilling. Should injury vident, the contractor shall be required to ream the holes the injured metal is removed and drive larger rivets. Should njury be of such extent that removing up to $\frac{1}{4}''$ larger than nal diameter of the holes will not remove the injured metal, member or part of member will be required.

ection 7. Concrete Floors.—Concrete floors on steel trusses not be placed until after the falsework has been removed and pan swung into place. In placing the concrete in the slab, the as shown on the plans should be followed. If there is no of concrete placement shown on the plans, the attention of

the bridge engineer shall be called to the fact and he will instructions.

"It is always safe to begin at the center of the span and wo both directions.

"The resident engineer shall see that counters are prop adjusted, that the turnbuckles are so adjusted that they have same number of turns in the barrel of the turnbuckles. Cour should be left loose until the span is swung. They should be tightened sufficiently to take out any slack which exists in member but only tightened to the point where they will take st

PART III

SPECIFICATIONS

The following clauses quoted from various sources are examples of current practice. They are not ideal but serve to show the points to be considered, and have been included to give condensed authoritative descriptions of construction operations. If the reader is preparing specifications he can obtain the most up-to-date ideas from the U. S. Bureau of Roads and the American Association of Highway Officials, who have prepared standard specifications covering all clauses of road and bridge work.

A specification should be complete, concise, and clear as to the materials, manipulation, and basis of measurement and payment. In preparing a specification it is convenient to have a general outline of points to be covered. Such an outline has been prepared by the U. S. Office of Public Roads to serve as a uniform basis for specifications for federal aid and is reproduced below. It is in the author's opinion a very good reminder of necessary requirements.

The usual size of page used for highway specifications is approximately $8\frac{1}{2}$ by 11″; this is an unwieldy size for field use; a size of 6 by 9″ is much handier and is about the smallest dimension feasible on account of space required on the proposal bidding blanks. Where much work is being done, the specifications proper can be printed in pocket form $4\frac{1}{4}$ by $6\frac{1}{2}$″ and the proposal, contract, and bond separately on the usual $8\frac{1}{2}$ by 11″ size. This makes a convenient combination for both the field men and for office filing of contract records.

Repetitions should be avoided. Segregating the requirements for materials in one part of the specification will prevent repetitions. Blanks to be filled out by hand are undesirable and should be reduced to a minimum. Loose-leaf specifications are poor practice. Printed bidding sheets containing the estimate quantities of work reduce possible complications in connection with comparing bids.

No attempt is made in this book to discuss methods of bidding or the legal forms of contract, as they must conform to local statutes.

STANDARD OUTLINE OF ROAD AND BRIDGE SPECIFICATIONS

Proposed as Standards of Practice U. S. Bureau of Public Roads (1925)

NOTE.—General headings and subheadings appear in the outline in the order and form in which, it is proposed, they should be used in Standard Specifications; each of these subheadings should cover pertinent subject matter, treated in the form and arrangement indicated. Subject matter to

be dealt with under each item and subheading is briefed, where not otherw clear and self-evident. To promote succinctness, as well as uniformity, selected typical phraseology appearing in this outline is suggested as standa It is not the intent that all subjects here outlined be covered in a st Standard Specification, if not involved in the work contemplated by a sta or required by law, but such headings, items, subheadings, and subject mat as are involved in a specification should appear in the order and form in cated in this outline. Such additional items, or general subjects w suitable headings, as are desired should be inserted in their logical posit in the outline. Such additional clauses or incidental paragraphs as desired should be placed following those shown in the item or article to wh they pertain.

Title Page or Cover for Specifications, Etc.

NOTE.—The name of the state should appear at the top of the title p in bold-faced caps.

Definitions and Terms

Definition of State, State Highway Department, or Commission, Engine Contractor, and all words or terms used in a special sense.

Proposal Requirements and Conditions

Contents of Proposal Forms.—Location and description of proj approximate estimate with schedule of items for which bid prices are invit special provisions, date, time, and place of opening.

Interpretation of Estimates.—Basis for comparing bids; statement rega ing right of engineer to increase or decrease quantities shown in propo Actual quantities to be paid for at unit prices.

Examination of Plans, Specifications, Special Provisions, and Site of Wo

Preparation of Proposal.—Requirement that proposal must be filled completely. Specific requirements as to signatures.

Rejection of Proposals Containing Alterations, Erasures, or Irregularit

Proposal Guaranty.—Form and amount required—if certified check, whom payable.

Delivery of Proposals.

Withdrawal of Proposals.

Public Opening of Proposals.

Disqualification of Bidders.—Because of submission of more than proposal, collusion, unbalanced proposals, lack of competency.

Competency of Bidders.—Criteria as desired by state.

Material Guaranty.—Showing by bidder of material sources and ma facture, and samples for approval may be required previous to awarc contract.

Any Additional Clauses Desired.

Award and Execution of Contract

Consideration of Bids.—Comparison of bids based on correct summat of items at prices bid. Right to reject any and all proposals and to wa technicalities.

Award of Contract.—By whom, place, to whom, and when made.

Return of Proposal Guaranties.—How and when returned.

Requirement of Contract Bond.—Reference to form furnished by st and to the amount, or to percentage of amount of contract required.

Execution of Contract.—Time and place.

Approval of Contract.—Reference to such formal approval as state or lo laws require.

Failure to Execute Contract.—After certain period, cause for annulme guaranty becomes property of state. Statement as to procedure with wo

Any Additional Clauses Desired.

Scope of Work

Intent of Plans and Specifications.—Statement that the intent is to scribe a complete work or improvement which the contractor undertake do, in full compliance with the plans, these specifications, the special visions, proposal and contract, including all earthwork, base and surf courses, structures, and incidental construction. Contractor to furnish required materials, equipment, tools, labor, and incidentals unless in cert cases otherwise provided in these specifications, the special provisions, posal, or contract.

ecial Work.—Statement that proposed construction or requirements not red by these specifications to be covered by special provisions, and ormed by contractor.

creased or Decreased Quantities of Work.—Engineer reserves right to quantities of work as found necessary or desirable without waiving or idating any condition or provision of contract. Contractor to perform as increased or decreased, and no allowance to be made for anticipated ts.

tra Work.—Unforeseen work made necessary by alteration of plans or ork or by other reason, involving increased or decreased unit cost to ractor, or work necessary to complete improvement for which no price is ided in contract, all to be performed in accordance with specifications as directed.

aintenance of Detours.—Statement indicating party responsible for, and ged with, roadway upkeep along detours during construction period.

moval and Disposal of Structures and Obstructions.—All obstructions, tures not designated for use, obstructing fences, telephone poles, etc., disposed of by the contractor as directed.

ghts in and Use of Materials Found on the Work.—Upon approval, ractor may make use of any material found in earthwork operations, for purpose for which it is suitable; when material so made use of was ded for use in embankment or otherwise, contractor to replace with valent quantity of material suitable for embankment.

nal Clearing Up.

y Additional Clauses Desired.

Control of the Work

thority of Engineer.—All work to be done under direct supervision of the neer, who shall decide all questions as to interpretation, materials, work, ress, disputes, and mutual rights between contractors, acceptable fulfil-, and compensation.

ans and Working Drawings.—Statement that plans will show in detail tures up to and including 20′ spans, lines, grades, typical cross-section nprovement, and general cross-sections; plans also will show general ares of bridges (over 20′ span). Supplementary bridge plans, shop ils, etc., as necessary to be furnished by contractor but not to be used to approval. Authorized alterations will be indorsed on approved s or shown on supplementary sheets. Additional details relative to ing drawings.

nformity with Plans and Allowable Deviations.—Statement that finished in all cases must conform with approved lines, grades, typical cross-on, and general cross-sections, except minor deviations authorized by neer in writing.

ordination of Specifications, Plans, and Special Provisions.—Statement a requirement in any one of the three is binding. In case of discrepancy, es to govern over scaled dimensions, plans over specifications, special isions over plans.

operation by Contractor.—Two sets of approved plans, specifications special provisions, and authorized alterations supplied to contractor; set must be kept available on work. English-speaking contractor's sentative to be available to receive and execute orders. Contractor to l interference with other contractors.

nstruction Stakes.—Furnished and set up by engineer to give line and e; contractor to furnish all additional stakes, templets, and other mate- and work necessary for marking and maintaining points and lines. hed surfaces to conform in all respects to lines, grades, and plans.

thority and Duties of Inspectors.—Inspectors employed by state to ct all work and material and report to engineer; and to note and sus-, if necessary, unsatisfactory work and reject work containing unsatis-ry materials, all pending final decision by engineer. Not authorized to specifications, nor accept any portion of work, nor act as foreman for ractor, nor interfere with management of work, nor to bind engineer in way.

spection.—Contractors to furnish engineer and inspector with every ty for complete inspection of work and of the preparation and manu-re of the materials, also to uncover questioned work if ordered; detailed edure in such cases.

moval of Defective and Unauthorized Work.—Defective work to be died or removed and replaced forthwith as directed, at contractor's

expense. Unauthorized work to be removed if so ordered. Or engi may replace and charge against contractor.

Final Inspection.—To be made within certain period subsequent to cleaning up following completion of project.

Any Additional Clauses Desired.

Control of Material

Source of Supply and Quality.—Statement that only approved mate conforming to requirements shall be used. Approved source of suppl stand approved only so long as the material conforms to requirements.

Samples and Tests.—Prescribed samples to be submitted by contra or producer for testing. Tests to be made in accordance with U. S. Dej ment of Agriculture *Bulletin* 1216 (or other recognized methods if desi Contractor to furnish facilities for verification of his scales and meas

Storage.—Preservation and fitness to be assured.

Defective Materials.—Materials not conforming to requirements : be rejected and removed from work, and replaced in an acceptable ma by contractor at his expense. Engineer may remove and charge ag contractor.

Any Additional Clauses Desired.

Legal Relations and Responsibility to Public

Laws to Be Observed.—Federal, state, and local; to save the state harn against all claims from violations.

Permits and Licenses.—Contractor to procure.

Patented Devices, Materials and Processes.

Restoration of Surfaces Opened by Permit.—Contractor not to a openings except on authorized permit. Repair work involved to be formed by contractor at expense of party making opening.

Federal Participation.—Contractor placed on notice that the work is t subject to inspection by the federal government, which is not, howeve party to the contract.

Sanitary Provisions.—Contractor to comply with Board of He requirements.

Public Convenience and Safety.—Comprehensive regulations and ins tions relative to handling the work to assure uninterrupted convenience safety to traffic and the public along or near the work. If desired, d here maintenance of half the roadway for traffic during construction. road to be closed to public except by express permission of the engine

Barricades and Warning Signs.—Contractor to provide; to be illumin at night.

Use of Explosives.

Protection and Restoration of Property.—Contractor not to trespass u damage, or neglect the rights of public or private property; to take cautions to protect same, also underground structures, monuments, trees; to restore at own expense where, directly or indirectly, is respon for injury occurring; or upon notice engineer may cause such restoration charge against moneys due or to become due contractor.

Responsibility for Damage Claims.—Contractor to assume when bro in suits for any damage, injury, or infringement resulting from his wor neglect; engineer may retain, sufficient to cover, moneys due, or to bec due, contractor.

Opening of Section of Highway to Traffic.—At option of engineer; such opening not an acceptance, and maintenance to be at contrac expense unless otherwise specifically provided.

Contractor's Responsibility for Work.—Does not cease until final acc ance by engineer in writing. Responsibility covers all injury to work f elements and traffic unless otherwise provided. Contractor to repair sa also to care for materials and unfinished work during suspension.

Personal Liability of Public Officials.

No Waiver of Legal Rights.

Any Additional Clauses Desired.

Prosecution and Progress

Subletting or Assignment of Contract.

Prosecution of Work.—Notice of beginning. Place of starting determi by engineer. Prosecuted at points as ordered. When resuming w subsequent to suspension, contractor to give due notice to engineer to af opportunity to reestablish inspection.

nitations of Operation.—Contractor not to open up work to the prej- of work already started or to inconvenience traffic more than is sary as determined by the engineer.

aracter of Workmen and Equipment.

mporary Suspension of Work.—Wholly or in part, at order of engineer, ise of unfavorable weather, or other essential conditions; or because of e on the part of the contractor to prosecute the work properly in dance with the contract, to carry out orders, to remove defective rial or work; but the contractor shall not suspend the work without ority.

termination and Extension of Contract Time for Completion.

ilure to Complete Work on Time.

nulment of Contract.—Detailed causes, procedure, and retent.

rmination of Contractor's Responsibility.—Contract to be considered plete when all work has been completed and accepted by engineer and estimate paid; contractor to be then released from further obligation t as set forth in his bond.

y Additional Clauses Desired.

Measurement and Payment

easurement of Quantities.—All work acceptably completed under the act to be measured by U. S. Standard Measures and quantities of work rmed to be computed based on such measurements. Linear base e, surface course, or pavement measurements to be along actual sur-, not horizontally. Structures to be measured according to neat line n on plan or ordered.

ope of Pavement.—Compensation provided, at bid prices, to be accepted ll payment for materials, labor, tools, and equipment necessary to rm and complete the work, also loss, damage, unforeseen difficulties, sks and patent infringements. Before payment contractor to satisfy eer as to liquidation of bills.

reased or Decreased Quantities.—Increased or decreased quantities of for which there are contract unit prices to be paid at such prices for quantities actually done with no allowance for anticipated profits. restrictive provisions as desired.

tra and Force Account Work.—Extra work to be paid either under a lemental Agreement or by Force Account as agreed before starting work. Supplemental agreement to be signed by both parties. Force unt to be done only upon written order. Detailed procedure relative rce account payment.

itted Items.—Provision that engineer may order items omitted from act, found unnecessary to the improvement without vitiating contract such restrictive provisions as desired.

rtial Payments.

ceptance and Final Payment.

y Additional Clauses Desired.

CONSTRUCTION DETAILS

Earthwork

scription.—Earthwork to consist of all clearing and grubbing, roadway drainage excavation, excavation for structures, embankment, borrow, haul, subgrade, shoulder, and subbase construction, all to be done by actor and paid for in accordance with these specifications.

Clearing and Grubbing

scription.—Specific requirements.

asurement and Payment.

Roadway and Drainage Excavation

scription.—This work shall consist of . . . , giving specific list of all and features of work desired to be included—"all in conformity with nes, grades and cross-sections shown on plans."

ssification.

nstruction Methods.

thod of Measurement.—In original position by average end area od; measurement of overbreak as desired.

sis of Payment.

Excavation for Structures

Description.—Statement of work included. (Not to overlap roa and drainage excavation.)

Construction Methods.—Depth, back fill, layers, compaction, etc.

Method of Measurement.—Allowance outside of neat structure lines.

Basis of Payment.

Embankment

Construction Methods.—Of suitable material; depth of layers, compac hillside embankment; responsibility.

Compensation.—Not to be paid for directly but to be considered pa work included in prices bid for excavation and borrow.

Disposal of Surplus Material

Statement of requirements. Not to be compensated for directly b be considered part of work included in prices bid for excavation and bo

Borrow

Description.—To consist of excavation, and disposal as directe satisfactory material obtained from borrow pits when material not avai from excavation to complete embankments.

Construction Methods.—No work prior to staking out; pits to be trin to permit measurement; to drain where practicable.

Method of Measurement and Basis of Payment.—In original positic average end areas or equivalent method.

Overhaul

Method of determination and basis of payment.

Subgrade

Description.—After earthwork substantially completed and all d laid, subgrade to be brought to lines, grades, and typical cross-section s on plans.

Construction Methods.—Soft and unstable material, also rock t removed; to be refilled with suitable material from excavation and bo Rolling clauses as desired; superficial scarifying of old stone or g roadways where reconstructed base course not ordered; highway and ra intersections.

Protection of Subgrade.—For surface courses; for pavements; no st or stock piling of material; no surfacing material to be placed or pave laid on frozen or muddy subgrade; nor on any subgrade prior to checkin approval.

Compensation.—As desired.

Shoulders

Description.—After earthwork substantially completed and all d laid, shoulders to be constructed of approved material, to elevation, w and shape shown on plans, and dressed as directed after surface cour pavement is completed.

Materials and Construction Methods.

Method of Measurement and Compensation.—As desired.

Subbase

Description.—Item to consist of special approved material, placed compacted in excavations made by removal of soft, unstable, or unsuitable subgrade materials; to be constructed where specifically ord

Materials.—Field or quarry stone, etc.; filler, slag, gravel, etc.

Construction Methods.—As desired (usually by cubic yard).

Finishing Earth-graded Roads

Description.—Where road to be finished as an earth-graded road wi surfacing other than earth, after all other earthwork and all structures pleted, roadway to be finished for travel, to lines, grades, and typical c section shown on plans.

Construction Methods.

Method of Measurement and Basis of Payment.

Fine Grading Subgrade and Shoulders

Description.—This work to consist of preparing a previously graded for immediate placement of surface courses or pavements.

Cstruction Methods.
Mhod of Measurement and Basis of Payment.—As desired; or may be pited as included under some other suitable item.

Base Courses

Reat the following outline for each kind of course desired.

Subgrade Treatment

Dcription.—Item to consist of granular or other stabilizing courses ucted on the subgrade in accordance with these specifications and ming in all respects with the lines, grades, and typical cross-section on plans.
Merials.
Cstruction Methods.
Mhod of Measurement and Basis of Payment.

——————Base Course
(Insert name)

Dcription.—Item to consist of a foundation course of etc. . . . conted on the subgrade or other completed base course in accordance with specifications, conforming in all respects, etc. (similar to above).
Merials.—Stone, sand, screenings, binder, etc.
Cstruction Methods.—Placing, rolling, etc.
Mhod of Measurement and Basis of Payment.

Surface Courses or Pavements

Surface Treatment

Dcription.—Indicate number of treatments and gallons to each treatf paid by square yard; or prescribe "item to consist of consecutive ents or amount and type of material noted on typical cross-section ns."
Merials.
Cstruction Methods.
Mhod of Measurement and Basis of Payment.—Preferably by square

——————Surface Course (or Pavement)
(Insert name)

Reat the following outline for each kind of surfacing or pavement. ge in order from lower types to higher. Each item should prescribe a t and straight-edge test of finished surface.
Dcription.
Merials.
Cstruction Methods.
Mhod of Measurement and Basis of Payment.—Details of measurement; cepted quantities of this item thus measured shall be paid for at the ct unit prices bid per square yard for (insert exact name), which price, as otherwise expressly provided, shall be full compensation for ning, hauling, and placing all materials, and for all labor, equipment, and incidentals necessary to complete the item.

Concrete Bridges

Dcription.—Concrete bridges to be built as indicated on plans, ming to line, grade, and dimensions shown, and in accordance with the cations for piling, concrete, reinforcing steel, and other items which ute the complete structure.
Merials.—Statement that materials shall be those prescribed for the l items which constitute the structure, with supplementary requirepertaining to bridges only, as desired.
Cstruction Methods.—Prescribe foundation preparation and construcalsework, sequence and method of casting, and details peculiar to construction. Manipulation and mixing of materials, concrete protection, etc., should be prescribed under concrete, except such ments peculiar to bridges as are desired here.
Dign.—May be detailed as desired here, or reference made to indepenridge Design section.
Mhod of Measurement and Basis of Payment.—Statement that the will be paid for by the actual quantities of the various items incorpo—piling, concrete of the various classes, reinforcing steel, and wearing urface complete in place at the unit prices bid for the several items

enumerated, which prices, except as otherwise expressly provided, sh full compensation for all work, materials, labor, and incidental work sary to complete the bridge ready for use.

Steel Bridges

Description.
Materials.
Construction Methods.
Design.—May be detailed as desired here, or reference made to inde ent Bridge Design section.
Method of Measurement and Basis of Payment.—Statement tha bridge will be paid for by the actual quantities of the various items porated—piling, concrete, reinforcing steel, structural steel, and we floors as desired, all complete in place at the unit price bid for the s items enumerated, which prices, except as otherwise expressly pro shall be full compensation for all work, materials, labor, and incidental necessary to complete the bridge ready for use.

Timber Bridges

Description.
Materials.
Construction Methods.
Design.—May be detailed as desired here or reference made to indepe Bridge Design section.
Method of Measurement and Basis of Payment.

Culverts and Retaining Walls

Description.—All concrete and masonry culverts, all pipe culvert walls, retaining walls to be built as indicated on plans conforming t grade, and dimensions shown and in accordance with the specificatic concrete, reinforcing steel, masonry, culvert pipe of the several va and other items which constitute the complete structure.
Materials.—Statement that materials shall be those prescribed f several items which constitute the structure.
Construction Methods.—Foundation conditions and involved prepa and construction. Pipe culverts to be constructed of the kind c indicated, suitably connected and laid. General requirements for joints, also for back filling.
Method of Measurement.—Quantities of various items for paymen actual amounts completed and accepted. Concrete and masonry computed from neat dimensions shown on plans or ordered in writin to be measured in place.
Basis of Payment.—Culverts, including pipe culverts and retaining to be paid for at contract unit prices bid for the several items which tute the completed structure, which prices, except as otherwise ex provided, shall be full compensation for all material, labor, equipment and incidentals necessary to complete the structure ready for use.

Concrete

Description.—Classification and classified uses, proportions.
Materials.—Specify composition and materials for each class. St and quality requirements.
Construction Methods.
Method of Measurement and Basis of Payment.

Reinforcing Steel

Description.
Materials.
Construction Methods.—Bending and placing.
Method of Measurement and Basis of Payment.

Structural Steel

Description.
Materials.
Construction Methods.
Method of Measurement and Basis of Payment.

——————————Masonry

(Insert name)

Repeat for each type.
Description.

aterials.
onstruction Methods.
ethod of Measurement and Basis of Payment.

Concrete Pipe

epeat for each kind of pipe.
escription.—Under this item concrete pipe conforming to these specifi-ons, of the sizes and dimensions shown on the plans, shall be furnished placed as directed.
aterials.
anufacture.
ethod of Measurement and Basis of Payment.
Cast-iron Pipe, Corrugated Galvanized Metal Pipe, Vitrified Pipe

Incidental Construction

escription, material, construction methods, method of measurement, and s of payment to be included under each of the following items.

g, Rip-rap, Cribbing, Underdrains, Gutters, Curbing, Guard Rails, Additional Items As Desired

Bridge Design

desired, design and design details of bridges may be grouped below, mentioned in Construction Details division by reference only. Such -reference must be expressly made.
eneral Design.—Loads, stresses, substructures and retaining-wall mptions, etc.
oncrete Design.
ructural Steel Design.
mber Structure Design.

Material Details

OTE.—If it be desired to group all materials in an independent division, erties, tests, and requirements for all materials should be detailed here. ich case the materials must be classified and defined as shown below and opriate cross-reference expressly made to them under the subcaption rials appearing in each item of Construction Details.
ementing Materials.—Portland cement, lime, etc.
ater.
ne Aggregate.—Filler dust, sand, grit, etc., for all purposes, including on-bituminous fillers.
oarse Aggregate.—Stone, gravel, slag, etc., for all purposes.
lford and Quarry Stone, etc.
asonry Stone, etc.
ving Brick and Blocks.
utminous Materials.
ilvert Pipes, Drain Tiles, etc.—Concrete, cast iron, corrugated metal, fied clay, etc.
etal Reinforcement.—Bars, mesh, expanded metal, etc.
ructural Steel.—Structural shapes, fabricated steel, etc.
iscellaneous Iron and Steel.—Castings, special wrought work, etc.
eated Timbers.
itreated Timbers.
ints, Oils, etc.
onuments.
iscellaneous Materials.—Fencing wire, cables, pipe rail, etc.

Forms

OTE.—Documents which pertain to the individual project and which their nature require filling out, completion or execution should be nged in the following order. If desired they may be bound in a separate phlet.

Notice to Contractors

me and place of receiving and opening proposals.
ief description of proposed work.
ace where plans and specifications may be examined or secured, and whom information may be obtained.
ghts reserved to reject any or all proposals.

Any additional information desired, such as competency of bidders.

NOTE.—The above information should be shown in the advertisement bids, and on the notice to contractors, which may be sent out to prospec bidders.

Special Provisions

Supplementing the specifications for the construction of . . . . (give the identification of proposed w such as road name, number, job number, etc.).

NOTE.—Under this section should be placed all supplemental specificat and exceptions, as pertain only to the particular project and contract posed and are not covered satisfactorily in the general specification divis and are not standard or common to all work for which the general sp fications may have been prepared such as:

Materials, etc., furnished by the state. All materials, equipment, or o facilities for prosecuting the work, furnished by the state to the contrac should be here listed, with conditions governing delivery, use, and retur

Statement relative to disposal of specific materials or structures foun the work and not to be used in the construction thereof.

Special stipulations and requirements intended to apply to the one pro only and to supersede corresponding stipulations and requirements as scribed in the general specifications.

Specifications for special structures, such as lift bridges, etc.

Materials Investigated on State Highway No. 8264

The following data concerning materials has been compiled by the York State Bureau of Highways. The information is as reliable as possible to obtain without actual development of pits or ledges but nei the quantity nor the continuance of quality is guaranteed. In all c prospective bidders are required to satisfy themselves as to the avail supply of materials and their relative location.

Materials similar to those designated and of acceptable quality from source will be accepted. Acceptable materials must be furnished from o sources whenever the sources here indicated fail in quality or quantity. bidders' attention is called to the General Specifications concerning Mate of Construction.

TABLE OF MATERIALS, AUGUST 30, 1926

Location

0.1 mile from Station 143 + 70. . . . .
. . . .
. . . .

Kind

Sand. . . . .
Sand. . . . .
Stone. . . . .

Source

Local commercial. . . . .
Approved commercial. . . . .
Approved commercial. . . . .

For Items Numbered

All items. . . . .
All items. . . . .
All items. . . . .

Test No.

G-6315
. . . .
. . . .

Attention of Bidders

All concrete pavement will be tested for thickness and quality of pavem Sections of pavement which are found to be more than one-quarter short of the specified thickness shall be removed and replaced at the Cont tor's expense.

All Portland Cement furnished on this contract must be bin-tes

Proposal

ces for name and address of bidder.

ailed description of location of roadway or structure, length and width facing or pavement, or length and type of structure, referring to the drawings, specifications, special provisions, etc., by their titles and ngs for identification. If the proposal bond form is used, it should be ed to or furnished with the proposal form.

ress (as "To the State Highway Department").

laration of the bidder that the only persons or parties interested in the sal as principals are those named therein; that the proposal is made t collusion with any other person, firm, or corporation; that he has lly examined the specifications, including special provisions, if any, at he has made a personal examination of the site of the work; that to furnish all the necessary machinery, tools, apparatus, and other of construction, and do all the work and furnish all the materials ed in the manner and time prescribed; that he understands that the ities are approximate only and subject to increase or decrease, and the ation of his willingness to perform increased or decreased quantities of t unit prices bid in accordance with the specifications at the unit prices the following proposal schedule.

nized proposal showing the approximate quantities with spaces for unit bid, as:

PROPOSAL SCHEDULE

Time for completing project..........working days

te N	Approximate quantities	Items with unit bid price written in words	Unit bid price	Amount bid
1		Cubic yards excavation for .... per cubic yard.......		
	Total.....			

TE.—Spaces should be left for filling in the unit prices both in words gures, as indicated. The items of work should be numbered in the and with the same titles and units of measure shown in the specifi s. The units of measure used should be as follows:

cubic yard for all volumes except the gallon for bituminous materials not weighed and the barrel for cement.

square yard for all surface measurements except the square foot for esh or expanded metal. Acre may be used for clearing and grubbing.

foot or mile for linear measurements.

ton of 2000 pounds for weights except the pound for steel and casting.

nit price each for any item desired.

posal to perform "extra work," or "force account."

posal to execute contract agreement and to begin work as prescribed complete work as bid in schedule (or as stated in proposal).

posal stating the amount of contract bond.

posal for guaranty of work until final completion and acceptance.

ement of enclosure of proposal guaranty, naming form, amount, and ions of forfeiture.

ced for signatures, titles, and individual addresses.

Proposal Bond

ase a proposal bond is used in lieu of a certified check, the form therefor be attached to or furnished with the proposal form.

Contract

form of contract should be as short as consistent with legal require-

notice to contractors, specifications, special provisions, proposal, and should be referred to and made a part of this agreement, and such nce should identify the specifications, plans, drawing, etc., by their c markings. When standard specifications approved by the Bureau

of Public Roads are to govern, identification must be made by date of f approval.

The federal government is not to appear as party to this agreement.

Contract Bond

Estimates

Estimates shall be made up in accordance with the order and un measure indicated in the proposal form.

Index

Itemized index to be placed at the end of the specifications instead this point if the foregoing documents are issued as separate pamphlet

General Clauses

For the best examples of general clauses the reader is referred to Sta Specifications of the American Association of Highway Officials.

Examples are not included in this book as they are rarely needed b or office men and can be readily obtained from local state or goverr bureaus free of charge.

MATERIALS[1]

NEW JERSEY SPECIFICATIONS

91. Requirements Governing Materials

91A. General Conditions Governing Their Use.—No materials sh used which do not conform with the requirements therefor as herein de All materials used in the construction of any of the items of work given estimate of quantities or in any additional or extra work that may b formed by the contractor, as herein provided, shall be furnished by th tractor. The materials required for the different items of constructi given under said items. The requirements governing the use of pat materials, products or processes are given in Article 14. Samples of a able materials are on file at the laboratory of the department, Taylo Quarry Place, Trenton, N. J., and will be shown to prospective b upon request. No materials shall be used until tested and released t testing engineer.

Railroad cars or barges, used for transporting such road materials as gravel, slag, sand, bituminous filler, Portland cement, bituminous ce oils, tars, etc., must be clean when any of these road materials are dep therein. Materials shipped in cars, the sides or bottoms of which are c with coal dust, manure, ashes, clay, loam, earth, hay, straw, etc., w rejected regardless of the quality of said materials. Railroad cars cont broken sides or bottoms must be repaired before any materials are dep therein.

Trucks, wagons or other vehicles used in hauling or transporting materials must be kept clean, in proper working condition, have s substantial bodies which will prevent materials from escaping ther during transit, and be approved by the Engineer before being used.

Materials which have been approved before shipment and are inju transit, during unloading or handling at the site of the work, shall n used until reapproved. During handling of all stone, sand or other mat which are to be used in concrete extra care must be taken that no ea subgrade gets mixed therewith.

All bituminous cements shall be shipped ready for use without fu fluxing at the mixing plant or roadside. Each carload of bitumino Portland cement must be sampled and released before being used. samples may be taken before shipment under special arrangement in case with the department, or, in default thereof, must be taken t engineer or inspector on arrival at the terminal nearest the work, or a other convenient point. Carloads of stone, sand, gravel and bitum paving mixtures shall be carefully examined by the inspector, but sha be unloaded until released by him. Materials appearing defective sh sampled and held until the sample taken has been tested by the te engineer. Any material condemned by the engineer shall be remov once from the roadway.

Cement and other materials liable to damage from the elemen exposure must be stored in proper structures which will prevent them

[1] State of New Jersey.

ming damaged. The method of storing and handling explosives and y inflammable materials will be governed by the local regulations for.

e quantities of materials required shall be determined by weight unless wise specified. The railroad shipping weights shall govern in deciding ctual amount furnished or used. The contractor, when requested, shall sh the department with the freight bills of all materials received.

B. Conditions Governing Approval of Materials.—No materials will be oved for use which do not comply with the requirements given therefor. approval of a given material is in effect only as long as the material lied is of the same character and composition as the sample approved. approval of a material for a particular purpose or for use in a specified ner does not approve its use for any other purpose or manner.

C. Methods Used in Testing Materials.—The methods to be used in ng the materials given herein are those on file at the office of the depart- at Trenton, and will be furnished to producers or manufacturers upon cation.

92. Broken Stone

l broken stone, regardless of type, must not contain more than five (5) ent of weathered or partly decomposed rock. When used in concrete be coated with a bituminous material it must be free from pieces coated rtly coated with mud, clay, loam or other foreign material, and must not in any other type of stone having a higher per cent of wear than that fied for the stone itself. All such stone must be shipped in clean cars. e shipped in dirty cars will be rejected. Any one given type of broken , as shipped, must not contain over ten (10) per cent of any other type one. Approved stone of different types cannot be mixed during use, used intermittently for any one given item of construction. All orders rushed or broken stone must state purpose for which it is to be used. stone must not contain more than five (5) per cent of slabs, flat or ated pieces, the width of which is less than five (5) per cent of the length. various stone fragments composing any particular size shall be uniformly buted throughout the mass of stone, as shipped. When two (2) or sizes of stone are mixed to secure any particular specified size, the g must be done before the stone is loaded into the shipping vehicle. following methods are suggested:

nultaneously feeding on belt conveyor proper proportions of the different

eding proper proportions of the different sizes through converging chutes the bin or stock pile from which the material is to be shipped.

versing screen plates or other arrangement of screens, which will insure perly graded material of the sizes desired.

ipments containing piles or layers of broken stone that are not uniform e rejected.

one intended for use in any Portland cement concrete or to be coated a bitumen, in addition to meeting the above requirements, must not in more than ten (10) per cent of stone coated or partly coated with dust. Stone which has become coated with mud, loam, clay or other gn material, either during transit or after receipt on site of work, must e used and shall be removed from the highway or storage site.

A. Sizes.—Permissible variations as to size of stone are shown in the below for each size and grade of stone. This table shows the minimum naximum allowable percentages passing the different screens and sieves. screens and sieves designated in the table are those used in the labora- of the department.

henever the words Trap, Granite, Dolomite, Limestone Gneiss, Sand- or Quartzite are used in these specifications, the rocks designated by shall comply with the following additional requirements respectively.

ap Rock.—A basic, igneous rock consisting principally of augite and oclase. It must be of medium or fine grain texture, show an even dis- tion of the constituent minerals, be of uniform quality and structure ghout, and have a per cent wear not greater than three (3).

nite.—An igneous rock consisting principally of quartz and feldspar. all be of medium or fine grain texture, show an even distribution of the ituent minerals, be of uniform quality and texture throughout, and a per cent wear not greater than four and one-half (4.5).

lomite.—A rock consisting principally of the carbonates of lime and esia. It must contain not less than thirty (30) per cent of magnesium nate, nor less than eighty (80) per cent of the combined carbonates of

Total Per Cent Passing

Grades and sizes	Laboratory screens, inches								Sieves		
	3½	3	2¼	1½	1¼	¾	½	¼	10	30	200
2½-in. "ballast"	100	90–100	0–25	...	0–5						
Concrete stone	...	100	95–100	...	25–60	0–15	0–5				
1½-in. stone	...	100	95–100	...	0–15	0–5					
¾-in. stone	...	......	......	100	95–100	0–25	0–5				
Screenings—Grade A,[1]	...	......	......	...	100	95–100	50–85	35–70	.....	10–30	0–5
Screenings—Grade B	...	......	......	...	100	95–100	......	40–80	.....	25–65	5–20
Dustless screenings	...	......	......	...	100	95–100	25–75	0–25	0–5		
Stone dust—Grade A,[2]	...	......	......	...	......	......	100	95–100	70–90		
Stone dust—Grade B	...	......	......	...	......	100	95–100	90–100			

[1] Screenings Grade A shall be made from recrushed stone only.
[2] Stone dust Grade A shall be made from recrushed stone only.

It is suggested that stone-crushing plants be equipped with the following screens: 3½, 3, 2¼, 1¼, ¾ in., and a dust jacket with 5/16-in. openings if round, or ¼-in. if square. If any special sizes of stone are required, additional screens will be needed.

The type and size of broken stone required for the different items of construction are specified under said items.

and magnesia. It must be of uniform quality and texture throughout, a per cent wear not greater than 3.5 and be of such density that it will be noticeably affected by five (5) immersions in a saturated solution of um sulphate with proper dehydration after each immersion.

mestone.—A rock consisting principally of the carbonates of lime and nesia. It must contain not less than fifty-five (55) per cent of calcium onates, nor less than eighty (80) per cent of the combined carbonates ne and magnesia, have a per cent wear not greater than six (6), and be of a density that it will not be noticeably affected by five (5) immersions saturated solution of sodium sulphate with proper dehydration after immersion.

eiss.—A rock containing pratically the same minerals as granite, but ng these minerals arranged in strata. It must have a dense structure the lines of stratification not so distinctly formed that the stone breaks in pieces or slabs. It must have a per cent wear not greater than four one-half (4.5).

ndstone or Quartzite.—A rock belonging to either of these two types shall ain not less than ninety (90) per cent of quartz, be of uniform quality and ure, free from seams, lines of clay, distinct cleavage planes, or lines of ification which will cause the stone to break into three slabs or pieces. ust have a per cent wear not greater than four and one-half (4.5).

93. Slag

l slag must be air cooled, have a fresh, clean surface, free from mud, dirt, or loam. It must not be brittle nor glassy nor have an apparent specific ity greater than 3.0 at 15.5°C. When used for concrete it must produce ncrete which will have an average compressive strength of not less than lb. per square inch when twenty-eight (28) days old, having the same position and consistency, and tested in the same manner given here r Broken Stone. It must weigh not less than seventy (70) pounds per foot loose measure, and be free from decomposed products. The irements governing the different sizes will be the same as for broken e. Slag containing more than one and one-half (1½) per cent of sulphur not be used in reinforcement concrete.

94. Gravel

avel shall be divided into two general classes: Washed gravel and road el.

A. Washed Gravel.—Washed gravel may be composed partially or ly of crushed pebbles, but must be free from soft, thin, elongated pieces, nic matter, loam, clay, or pebbles coated therewith. It shall contain pebbles of a sound, hard, durable character, and must be uniform mposition, free from weathered, decomposed pebbles, pieces of coal or r foreign materials. It shall not contain more than 5 per cent of slate, or soft sandstone particles, having a per cent wear greater than. . . . hen tested by means of laboratory screens and sieves the various sizes ashed gravel shall conform to the following requirements:

TOTAL PER CENT PASSING

Sizes	Laboratory screens, inches					Sieves
	2¼	1½	1¼	½	¼	10-mesh
1 in.	100	...	0–25	0–5		
¾ n.	...	100	75–100	0–25	0–5	
C crete gravel[1]	100	...	25–50	0–12	0–2	
P gravel	...	...	100	95–100	0–25	0–5

[1] Concrete gravel size may be prepared by mixing two (2) parts of one and half (1½) inch gravel with one (1) part of three-quarter (¾) inch gravel olume; however, when thus prepared, these two sizes must be mixed in a manner that will insure a uniformly graded product, conforming to the n requirements given below. The method employed in mixing in each must be approved by the department before using.

94B. Road Gravel.—Road gravel shall be composed of sand and h durable pebbles of quartz, mixed with clay in such proportions that the gr will comply with the grading and other requirements specified herein be and also compact under travel into a hard, dense pavement. It shall con not less than eight (8) nor more than twenty (20) per cent by weigh material removed by the elutriation test, and the gravel having the material thus removed shall, when tested by means of laboratory scr and sieves, comply with the requirements given below:

TOTAL PER CENT PASSING

Grades	Screens, inches					Siev
	2	1½	1	½	¼	10
A	100	95–100	85–100	55–90	45–80	35–7
B	...	100	95–100	90–100	75–95	60–8

95. Sands

Sands shall consist of grains or particles of quartz or other hard durable rocks, the surfaces of which are not coated with any foreign mat nor worn smooth. The grains shall be moderately sharp, free from decomposed or partly decomposed sand grains, lumps of clay, or ferrugi cemented sand, mica, loam, sea salts, organic matter, or other materia

Sands shall be divided into two general classes, bituminous sands concrete sands.

95A. Bituminous Sands.—Bituminous sands are those intended fo in the construction of bituminous pavements, bituminous mortars, bit nous filters, or mastics, and when tested by means of laboratory screens sieves shall conform to the following requirements:

Passing	Retained on	Minimum, %	Maximum, %
¼-in. screen	10-mesh sieve	0.0	2.0
10-mesh sieve	30-mesh sieve	10.0	30.0
30-mesh sieve	50-mesh sieve	15.0	42.0
50-mesh sieve	80-mesh sieve	20.0	35.0
80-mesh sieve	200-mesh sieve	15.0	35.0
200-mesh sieve	....	....	5.0

95B. Concrete Sands.—Concrete sands are those intended for use Portland cement either in a Portland cement concrete or mortar, and w tested by means of laboratory screens and sieves should conform to following requirements:

Passing	Retained on	Minimum, %	Maximum, %
½-in. screen	¼-in. screen	....	1.0
¼-in. screen	10-mesh sieve	5.0	25.0
10-mesh sieve	30-mesh sieve	30.0	60.0
30-mesh sieve	50-mesh sieve	20.0	40.0
50-mesh sieve	200-mesh sieve	5.0	15.0
200-mesh sieve	....	....	5.0

crete sands must not contain more than four (4) per cent of material ed by the elutriation test and must produce a Portland cement mortar will have at the end of seven (7) and twenty-eight (28) days a crushing nsile strength equal to or greater than that of a mortar prepared in me manner, of the same proportions and consistency, using the same t, and Standard Ottawa sand.[1] The ratio of cement to sand is to be me as that specified for the concrete in which said sand is to be used. pproval of a sand for use in concrete of a given composition does not e its use in concrete having a different composition.

. **Stone Dust.**—Stone dust, Grade A, may be used as a concrete sand, ly after being approved by the engineer for this purpose, said approval pply only to the material that is actually represented by the sample. t produce a mortar having not less than one hundred and twenty-five er cent of the strength of a similar mortar prepared from Ottawa sand sted in the same manner as Concrete Sands.

. **Grout Sand.**—Sands intended for use in a Portland cement grout in addition to meeting the other general requirements given above, s a 10-mesh sieve and produce a Portland cement mortar which will t least seventy-five (75) per cent of the strength of a similar mortar ed with Standard Ottawa sand, and tested in the same manner as te Sands.

Cushion Sand.—Sands for use in the cushion course placed under blocks shall comply with the requirements for a concrete sand the mortar produced therefrom need only 75 per cent of the strength milar mortar prepared from Standard Ottawa sand and tested in the nanner as specified under Concrete Sand.

96. Portland Cement

cement shall comply with the requirements and be tested in the man- ecified by the A. S. T. M. standards, Serial Designation C9-21, with all uent changes or corrections.

Portland cement required for use will be shipped from bins previously ed by the State Highway Department. Copies of all Portland cement placed by the contractor with cement companies, direct or through s or local dealers, shall be forwarded to the department. When an s placed through a broker or local dealer, said broker or local dealer urnish the department with a copy of this order to the cement com- or the cement required. In all cases, regardless of whether the cement red by the contractors direct or through brokers, the order must be with the cement company at least ten (10) days previous to the date initial shipment. The extra cost, if any, required for shipment from usly approved bins shall be borne by the contractor and will not be r by the department.

Portland cement shall be shipped in cloth bags, which are plainly ed with the manufacturer's name and brand of cement contained . Each bag shall contain ninety-four (94) pounds of cement net and be considered as containing one (1) cubic foot of cement.

s of cement which for any reason have become partially set on the or which contain lumps or partly set cement shall be rejected.

erent brands, makes, or grades of cement, must be piled by themselves. ved cements cannot be mixed during use, or used intermittently in any en item of construction.

ement must be stored in bins prepared for this purpose and shipment nly from these bins. All cars shall be loaded under the supervision sealed by a representative of the State Highway Commission. Cars d at their point of destination with seals broken or destroyed may be ed, but should not be used until resampled and approved.

lucers are requested not to permit shipments to be made of any cement es not comply with the requirements given. It is assumed that all shipped complies with the requirements given herein. All shipments ontaining cement that does not comply with the requirements given shall be replaced with cement that does comply with said requirements.

er used with Portland cement shall be clean, free from oil, acid, alkali, ts, or vegetable matter.

[1] awa Sand is furnished by the Ottawa Silica Co. of Ottawa, Ill. One d per cent passes a No. 20 sieve and 100 per cent is retained on a sieve. It has about 37 per cent of voids and a fineness modulus of

Item 19A. Special Cement (Quick Hardening)[1]

Under this item the contractor shall furnish and place cement meeti following requirements:

A pat of neat cement shall remain firm and hard, and show no si distortion, cracking, checking, or disintegration in the steam t soundness.

The cement shall not develop initial set in less than 45 min. when the needle is used or 60 min. when the Gillmore needle is used. Final shall be attained within 10 hr.

The average tensile strength in pounds per square inch of not less three standard mortar briquettes composed of 1 part cement and 3 standard sand, by weight, shall be equal to or higher than the following

Age at Test, Days	Storage of Briquettes	Ten Stre Pound Square
1	1 day in moist air	3(
7	1 day in moist air, 6 days in water	3:
28	1 day in moist air, 27 days in water	4(

The average tensile strength of standard mortar at 7 days shall be than the strength at 1 day and the average tensile strength of sta mortar at 28 days shall be higher than the strength at 7 days.

The cement shall be tested in accordance with the methods of te given in the Standard Specifications of the American Society for T Materials, Serial Designation C-9-21.

All cement shall be sampled as directed by the Bureau.

Measurement and Payment.—The quantity to be paid for shall number of barrels, of 376 lb. net weight, incorporated in the w accordance with the specifications and to the satisfaction of the en

97. Mineral Fillers

Fillers for use in a bituminous mortar, bituminous concrete, or asphalt shall be Portland cement, ground limestone, or pulverized li less than eighty-five (85) per cent of which must pass a one hundrec mesh sieve and sixty-five (65) per cent a two hundred (200) mesh sie shall be free from lumps or balls or any foreign material that may in for the purpose intended.

98. Bituminous Cement

Must be uniform, homogeneous, and free from water. They mus the requirements designated below for the respective type of pavem which they are intended to be used. They must have the consiste quired herein before shipping, for fluxing will not be allowed at the plant.

99. Asphaltic Cements and Oils

Asphaltic cements may be made from petroleum or from fluxed or un natural asphalts, and must be free from tar or tar products.

[1] To get quick-hardening concrete b other methods, see p. 485.

99A. Prepared from Natural Asphalts.

Grades	NA-1		NA-2		NA-3		NA-4		NA-5	
Tests	Min.	Max.	Min.	Max.	Min.	Max.	Min.	Max.	Min.	Max.
1. Specific gravity at 15.5°C.	1.045	......	1.045	......	1.04	......	1.04			
2. Penetration at 25°C., 100 g.—5 sec.	40	50	50	60	75	95	90	150	10	20
3. Penetration at 46°C., 50 g.—5 sec.	......	......	......	......	......	......	......	......	......	80
4. Evaporation loss at 163°C., 20 g.—5 hour, per cent.	1.50	3.0	1.50	3.00	1.50	3.50	1.50	4.0	......	3.0
(a) Penetration on residue at 25°C., 100 g.—5 sec.	20	......	25	......	35	......	45	......	5	
5. Solubility in benzol, C_6H_6, per cent.	95.00	98.00	95.00	98.00	95.00	98.00	95.00	98.00		
6. Bitumen soluble in ether $(C_2H_5)_2O$, per cent.	85.00	......	85.00	......	85.00	......	85.00			
7. Bitumen soluble in carbon tetrachloride, CCl_4, per cent.	99.00	......	99.00	......	99.00	......	99.00			
8. Flash point in °C.	175	......	175	......	175	......	165			
9. Ductility at 50 penetration (cm.)	50.0	......	50.0	......	50.0	......	50.0	......	25.0[1]	
10. Paraffin scale.										

[1] Taken at 20 penetration.

99B. Petroleum Residua Prepared from Heavy Mexican Petroleum.

Grades	H.M.[1]		H.M.[2]		H.M.[3]		H.M.[4]			
Tests	Min.	Max.	Min.	Max.	Min.	Max.	Min.	Max.	Min.	Max.
1. Specific gravity at 15.5°C	1.04	......	1.035	......	1.035	......	1.03			
2. Penetration at 25°C., 100 g.—5 sec	45	55	55	65	75	95	90	150		
3. Penetration at 46°C., 50 g.—5 sec	......	300	......	360						
4. Evaporation loss at 163°C., 20 g.—for 5 hour, per cent	......	1.00	......	1.00	......	1.50	......	1.50		
(a) Penetration on residue at 25°C., 100 g.—5 sec	30	......	35	......	45	......	50			
5. Solubility in benzol, C_6H_6, per cent	99.80	......	99.80	......	99.80	......	99.80			
6. Solubility in ether, $(C_2H_5)_2O$, per cent	75.00	......	75.00	......	75.00	......	75.00			
7. Solubility in carbon tetrachloride, CCl_4, per cent	99.00	......	99.00	......	99.00	......	99.00			
8. Flash point in °C	225	......	215	......	210	......	200			
9. Ductility at 50 penetration (cm.)	100	......	90	......	80	......	70			
10. Paraffin scale, per cent	......	1.25	......	1.25	......	1.50	......	1.75		

99C. Petroleum Residua Prepared from Light Mexican Petroleum.

Grades	L.M.[1]		L.M.[2]		L.M.[3]		L.M.[4]			
Tests	Min.	Max.	Min.	Max.	Min.	Max.	Min.	Max.	Min.	Max.
1. Specific gravity at 15.5°C.	1.035	......	1.030	......	1.030	......	1.025			
2. Penetration at 25°C., 100 g.—5 sec.	45	55	55	65	75	95	90	150		
3. Penetration at 46°C., 50 g.—5 sec.	......	300	......	360						
4. Evaporation loss at 163°C., 20 g.—for 5 hour, per cent.	......	1.00	......	1.00	......	1.50	......	1.50		
(a) Penetration on residue at 25°C., 100 g.—5 sec.	30	......	35	......	45	......	50			
5. Solubility in benzol, C_6H_6, per cent.	99.80	......	99.80	......	99.80	......	99.80			
6. Solubility in ether, $(C_2H_5)_2O$, per cent.	75.00	......	75.00	......	75.00	......	75.00			
7. Solubility in carbon tetrachloride, CCl_4, per cent.	99.00	......	99.00	......	99.00	......	99.00			
8. Flash point in °C.	225	......	215	......	210	......	200			
9. Ductility at 50 penetration (cm.)	100	......	90	......	80	......	70			
10. Paraffin scale, per cent.	......	3.50	......	3.75	......	4.00	......	4.50		

99D. Petroleum Residua Prepared from California Petroleum.

Grades	C.[1]		C.[2]		C.[3]		C.[4]			
Tests	Min.	Max.	Min.	Max.	Min.	Max.	Min.	Max.	Min.	Max.
1. Specific gravity at 15.5°C	1.025	......	1.02	......	1.02	......	1.015			
2. Penetration at 25°C., 100 g.—5 sec	40	50	50	60	70	90	90	150		
3. Penetration at 46°C., 50 g.—5 sec										
4. Evaporation loss at 163°C., 20 g.—for 5 hour, per cent	......	0.75	......	1.00	......	1.25	......	1.50		
(*a*) Penetration on residue at 25°C., 100 g.—5 sec	20	......	25	......	30	......	35			
5. Solubility in benzol, C_6H_6, per cent	99.80	......	99.80	......	99.80	......	99.80			
6. Solubility in ether, $(C_2H_5)_2O$, per cent	85.00	......	85.0	......	87.0	......	89.00			
7. Solubility in carbon tetrachloride, CCl_4, per cent	99.00	......	99.00	......	99.00	......	99.00			
8. Flash point in °C	210	......	205	......	200	......	175			
9. Ductility at 50 penetration (cm.)	150.0+	......	150.0+	......	150.0+	......	150.0			
10. Paraffin scale										

99E. Petroleum Residua Prepared by Blending California and Mexican Residua.

Grades	C.M.[1]		C.M.[2]		C.M.[3]		C.M.[4]			
Tests	Min.	Max.	Min.	Max.	Min.	Max.	Min.	Max.	Min.	Max.
1. Specific gravity at 15.5°C	1.03	......	1.025	......	1.02	......	1.02			
2. Penetration at 25°C., 100 g.—5 sec	45	55	55	65	75	95	90	150		
3. Penetration at 46°C., 50 g.—5 sec										
4. Evaporation loss at 163°C., 20 g.—for 5 hour, per cent	......	1.00	......	1.00	......	1.50	......	1.50		
(*a*) Penetration on residue at 25°C., 100 g.—5 sec	25	......	30	......	40	......	45			
5. Solubility in benzol, C_6H_6, per cent	99.80	......	99.80	......	99.80	......	99.80			
6. Solubility in ether, $(C_2H_5)_2O$, per cent	80.0	......	80.0	......	82.0	......	83.0			
7. Solubility in carbon tetrachloride, CCl_4, per cent	99.00	......	99.00	......	99.00	......	99.00			
8. Flash point in °C	220	......	215	......	205	......	190			
9. Ductility at 50 penetration (cm.)	125.0	......	125.0	......	100.0	......	100.0			
10. Paraffin scale, per cent	......	2.25	......	2.25	......	2.50	......	2.75		

99F. Petroleum Residua Prepared by Blending Mexican and Semiasphaltic Base Petroleums.

Grades	T.[1]		T.[2]		T.[3]		T.[4]			
Tests	Min.	Max.	Min.	Max.	Min.	Max.	Min.	Max.	Min.	Max.
1. Specific gravity at 15.5°C.	1.00	......	1.00	......	1.00	......	1.00			
2. Penetration at 25°C., 100 g.—5 sec.	45	55	55	65	75	95	90	150		
3. Penetration at 46°C., 50 g.—5 sec.	......	275	......	325						
4. Evaporation loss at 163°C., 20 g.—for 5 hours, per cent	......	1.0	......	1.0	......	1.0	......	1.0		
(a) Penetration on residue at 25°C., 100 g.—5 sec.	30	......	35	......	45	......	50			
5. Solubility in benzol, C_6H_6, per cent	99.5	......	99.50	......	99.5	......	99.5			
6. Solubility in ether, $(C_2H_5)_2O$, per cent	70.0	......	70.0	......	70.0	......	70.0			
7. Solubility in carbon tetrachloride, CCl_4, per cent	99.0	......	99.0	......	99.0	......	99.0			
8. Flash point in °C.	175	......	175	......	175	......	175			
9. Ductility at 50 penetration (cm.)	30.0	......	30.0	......	30.0	......	30.0			
10. Paraffin scale										

G. **Asphalt Cement Emulsion.**—*General:* The emulsion shall be homo-
ous, of such character that it will mix with water in all proportions and
ich stability that it will remain constant and uniform while being com-
d and mixed with clean, wet, crushed stone. Its consistency shall be
as uniformly to coat the stone and remain constant while being handled.
one Test: One (1) pound of dry, clean, trap rock screenings, Grade A,
be washed until clean and surplus water allowed to drain off for a period
e (5) minutes.
this clean, washed, crushed stone screenings shall be added one and
quarter (1¼) ounces of the emulsion. The mixture will then be con-
tly agitated by stirring, turning and mixing for a period of three (3)
ites.
y material that will not retain its emulsified characteristics without
eciable separation during such agitation will be rejected as being unsuited
he purpose for which it is intended.
alysis of Emulsion: When distilled up to a temperature of 260°C. the
loss shall not exceed thirty-two (32) per cent and not more than two (2)
ent of this distillate shall be other than water. The residue from the
oing distillation shall comply with the following requirements:

Grade	A.E.					
Tests	Min.	Max.	Min.	Max.	Min.	Max.
Specific gravity at 25°C..	1.01					
Penetration at 25°C., 100 g.—5 sec........	150	250				
Solubility in CS_2, per cent	98.5					
Fixed carbon, per cent...	6.0	15.0				
Ash, per cent...........	.....	1.0				
Ductility at 25°C. (cm.)..	40.0					
Paraffin scale, per cent...	.....	4.7				

99H. Asphaltic Oils.

Nature of oils	Dust oil		Slow curing oil		Rapid curing oil		Cut back light		Cut back heavy		Hot oil light		Hot oil heavy	
Grades	D.O.		S.C.O.		R.C.O.		L.K.		H.K.		L.H.O.		H.H.O.	
Tests	Min.	Max.	Min.	Max.	Min.	Max.	Min.	Max.	Min.	Max.	Min.	Max.	Min.	Max.
1. Specific gravity at 15.5°C.	0.92	.....	0.93	.....	0.90	.....	.....	.....	.....	.....	0.95	.....	1.00	
2. Evaporation loss on 20 g. at 163°C. —for 5 hours, per cent	8.0	25.0	12.0	.....	20.0	.....	35.0	.....	30.0	.....	5.0	12.0	.....	5.0
(a) Penetration on residue at —25°C., 100 gm.—5 sec.	.....	.....	.....	.....	75	.....	45	90	45	90				
(b) Float test at 50°C. (seconds)	10	30	20	.....	150									
3. Evaporation loss on 20 g. at 100°C. —for 5 hours, per cent	.....	3.0	4.0	15.0	10.0	.....	25.0	.....	20.0					
	25°C.		46°C.		46°C.		25°C.		25°C.		90°C.		90°C.	
4. Viscosity—temperature (first 50 c.c., Engler)—seconds	225	450	175	300	275	450	180	325	600	1200	300	600	600	1200
5. Solubility in benzol, C_6H_6, per cent	99.5	.....	99.5	.....	99.5	.....	99.5	.....	99.5	.....	99.5	.....	99.5	
6. Ductility, at 50 penetration (cm.)	.....	.....	.....	.....	20.0	.....	70.0	.....	70.0	.....	20.0	.....	20.0	
7. Asphaltic content at 100 penetration, per cent	40.0	50.0	50.0	65.0	60.0	75.0	55.0	65.0	60.0	70.0	75.0	85.0	85.0	95.0
8. Flash point in °C.	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	140	.....	160	

100. Tars

...ar may be either coal tar or petroleum water gas tar. They must comply ... the following requirements:

100A. Coal Tars.

Grades	A		B		X		KP					
Tests	Min.	Max.	Min.	Max.	Min.	Max.	Min.	Max.	Min.	Max.	Min.	Max.
1. Water content, per cent	.....	0.00	.....	2.0	.....	0.00	.....	2.0				
2. Specific gravity at 15°C	1.20	1.28	1.12	1.18	1.22	1.30	1.15	1.20				
3. Float test at 50°C. in seconds	35	75										
4. Melting point (B. & R.), °C	.....	.....	.....	.....	30	36						
5. Viscosity Engler at 40°C., first 50 c.c. (seconds)	.....	.....	100	150								
6. Viscosity Engler at 80°C., first 50 c.c. (seconds)	.....	.....	.....	.....	.....	.....	40	60				
7. Free carbon, per cent	12.0	20.0	4.0	12.0	12.0	25.0	12.0	25.0				
8. Distillation 0°C.–170°C., per cent	.....	0.1	.....	7.0	.....	0.1	.....	10.0				
9. Distillation 0°C.–235°C., per cent	.....	10.0	.....	18.0	.....	3.0	.....	23.0				
10. Distillation 0°C.–270°C., per cent	.....	18.0	.....	30.0	.....	12.0	.....	27.0				
11. Distillation 0°C.–300°C., per cent	.....	28.0	.....	35.0	.....	15.0	.....	32.0				
12. Specific gravity of entire distillate	1.02	.....	1.01	.....	1.03	.....	0.98					
13. Melting point of distillation residue												

100B. Water-gas Tars.

Grades[1]	UA		UB		UC		UD		U^2		U^3		U^4	
Tests	Min.	Max.	Min.	Max.	Min.	Max.	Min.	Max.	Min.	Max.	Min.	Max.	Min.	Max.
1. Specific gravity at 25°C.	1.09	1.13	1.10	1.14	1.09	1.145	1.110	1.155	1.14	1.18	1.15	1.185	1.16	1.19
2. Float test at 50°C. (sec.)	.....	.....	.....	.....	.....	.....	.....	.....	50	75	80	110	115	145
3. Viscosity at 40°C., 1st 50 c.c.—Engler (sec.)	80	120	250	350	400	500	700	800						
4. Free carbon (using CS_2 cold), per cent	.....	5.0	.....	5.0	.....	5.0	.....	5.0	.....	5.0	.....	5.0	.....	5.0
5. Distillation—total up to 170°C., per cent	.....	3.0	.....	2.0	.....	3.0	.....	2.0	.....	*Nil.*	.....	*Nil.*	.....	*Nil.*
6. Distillation—total up to 235°C., per cent	.....	18.0	.....	15.0	.....	20.0	.....	18.0	.....	4.0	.....	3.0	.....	2.0
7. Distillation—total up to 270°C., per cent	.....	35.0	.....	30.0	.....	30.0	.....	28.0	.....	13.0	.....	11.0	.....	9.0
8. Distillation—total up to 300°C., per cent	.....	45.0	.....	40.0	.....	40.0	.....	38.0	.....	26.0	.....	22.0	.....	18.0
9. Melting point of distillation residue (B. & R.), °C.	.....	60	.....	60	.....	60	.....	60	.....	65	.....	65	.....	65

[1] Grades UA, UB, UC and UD are to be prepared by cutting back U^3 with a suitable distillate.

;END OF ASPHALTIC CEMENTS, ASPHALTIC OILS AND TARS

Intended use	Grades that may be specified
ıeet asphalt, type S. A.	N. A.-1, H. M.-1, L. M.-1, C-1, C. M.-1, or T.-1
tuminous concrete surfaces, mixed hot, Type F. A.-B. C.-1, F. A.-B. C.-2, or W-B.	N. A.-2, H. M.-2, L. M.-2, C-2, C. M.-2, or T.-2
tuminous concrete surfaces, mixed cold, type A.	N. A.-3, H. M.-3, L. M.-3, C-3, C. M.-3, orT.-3
tuminous macadam surfaces, penetration method.	N. A.-4, H. M.-4, L. M.-4, C-4, C. M.-4, T-4, X., or U-4
tch work, hot-mixing method.	H. H. O., X., or U-4
tch work, cold-mixing method.	L. K., H. K., P., or U. C
rface treatments, cold application—macadam	S. C. O., R. C. O., B., U. B., or U. C
Bituminous concrete	L. K., or H. K
rface treatment, hot application—macadam	L. H. O., H. H. O., A., or U-2

101. Bituminous Waterproofing Compounds

l bituminous waterproofing paints shall be prepared ready for use before ment and shall be shipped in strong, substantial containers, plainly ced with the name and weight of content and name and address of the ufacturer. When so requested, the analysis of all paints furnished be supplied by the manufacturer within ten (10) days after request ade.

1A. Tar Paints.—Tar paints shall be prepared from a refined coal tar ater-gas tar and a tar distillate. They shall be free from water or petro- distillates, and must comply with the following requirements:

Grades	T P-1		T P-2		T P-2	
Tests	Min.	Max.	Min.	Max	Min.	Max.
Viscosity at 25°C., first 50 c.c Engler (seconds)	325	400	275	350	275	350
Free carbon (using hot benzol, C_6H_6), per cent	8.0	14.0	12.0	18.0	4.0	10.0
Distillation:						
0°–170°C., per cent	20.0	28.0	12.0	20.0	12.0	20.0
0°–235°C., per cent	0.0	37.0	15.0	35.0	15.0	35.0
0°–270°C., per cent	0.0	39.5	0.0	39.5	0.0	41.0
0°–300°C., per cent	0.0	41.5	0.0	43.5	0.0	46.0
Melting point of distillation residue (Ball & Ring) °C	60	70	55	70	55	70

101B. Asphaltic Paints.—Asphalt paints shall be prepared from petro residue or natural asphalts, and a petroleum or tar distillate. They be free from water, animal or vegetable oils, fats or greases, and shall co with the following requirements:

	A P^{-1}					
	Min.	Max.	Min.	Max.	Min.	M
1. Evaporation loss at 163°C. on 20 g. for 5 hours, per cent....	45.0					
(*a*) Penetration on residue at 25°C. (100 g.–5 sec.)..........	10	20				
2. Evaporation loss at 100°C. on 20 g. for 5 hours, per cent.....	35.0					
3. Solubility in benzol, C_6H_6						
(Prepared from petroleum asphalt), per cent.............	99.5					
(Prepared from natural asphalt), per cent....................	95.0					
4. Ductility at 50 penetration at 25°C., centimeters....	20.0					
5. Viscosity at 25°C. (Engler, first 50 c.c.), seconds.............	200	300				
6. Asphaltic content at 100 penetration, per cent............	50.0	60.0				

102. Wood Preservatives

Wood preservatives used in the pressure treatment of wooden b piling, etc., shall be either an oil distillate from coal-gas tar coke-ove or a product of which at least sixty-five (65) per cent shall be a distill coal-gas tar or coke-oven tar, and the remainder shall be refined or fi coal-gas tar or coke-oven tar. Only one type of preservative shall be on any one contract. They must comply with the following requireme given under W P^{-1} and W P^{-2}.

Wood preservatives used in the open-tank treatment of guard rail or other timbers shall be an oil obtained by distillation from coal tar or oven tar, and shall be free from any admixture of undistilled tar, wat tar, or tars or oils obtained from any other sources. The oil shall co to the following specifications given under W P^{-3}.

Grades	W P-1		W P-2		W P-3	
Tests	Min.	Max.	Min.	Max.	Min.	Max.
Water content, per cent.......	.....	3.0	.....	3.0	.....	1.0
Solubility in benzol, C_6H_6, per cent......................	99.5	...	97.0	...	99.75	
Specific gravity at 38°C./38°C., per cent....................	1.06	...	1.07	1.14		
Specific gravity at 38°C./15°C.	.....	...	.....	...	1.09	1.13
Distillates (based on water-free oil), 0°C.–210°C., per cent ..	.....	5.0	.....	5.0		
Distillates (based on water-free oil), 0°C.–235°C., per cent ..	.....	15.0	.....	25.0	.....	2.50
Distillates (based on water-free oil), 235°C.–300°C., per cent	.....	...	.....	...	.....	20.0
Float test at 70°C. on distillation residue above 355°C., if over 10 per cent, inches.....	.....	50				
Float test at 70°C., on distillation residue above 355°C., if over 35 per cent, inches.....	.....	...	.....	80	.....	25
Per cent of residue above 355°C....................	....	...	.....	...	.....	50.0
Specific viscosity, Engler at 20°C. on 200 c.c............	.....	...	.....	...	10	
Specific gravity at 38°C./15.5°C. of fraction between 235° and 315°C......	1.03	...	1.02			
Specific gravity at 38°C./15.5°C. of fraction between 315°C. and 355°C ..	1.09	...	1.09			
Coke residue, per cent........	..	2.0	.....	10.0	.....	2.0
Tar acids (per cent of total distillates), per cent...........	.....	...	.....	...	.....	15.0
Flash point (Cleveland open cup), °C..................	.....	...	.....	...	120	
Fire point (Cleveland open cup), °C..................	.....	...	.....	...	165	
All to be liquid (no solid), °C...	.....	...	.....	...	21	

103. Joint Fillers

e material used in filling joints in pavements, curbs, gutters, etc., shall vided into two grades, Grade P, poured joint fillers, and Grade M, ed joint fillers.

e poured joint fillers shall be prepared from either a coal tar or an ilt cement, complying with the requirements given below.

olded joint fillers shall be prepared by impregnating such inert materials t, woolen or cotton fiber, paper pulp, sawdust, etc., with a bituminous nt complying with the requirements given below. The inert material be applied as a layer on the outside of a bituminous sheet, or may be rmly distributed through the bituminous material. In either case ient inert material must be used to prevent the joint from chipping g cold weather.

olded joint fillers shall be cast in sheets, the thickness of which shall e same as the joint width specified, but in no case shall molded joint be cast in sheets less than one-half (½) inch nor more than three-ers (¾) inch thick. When no special width is specified the joints shall st in sheets from one-half (½) inch to five-eighths (⅝) inch thick.

molded joint fillers to be used in transverse joints in a concrete pave-shall be cast in lengths equal to one-half the width of the pavement, a width of one-half (½) inch greater than the thickness of the pave-

ment, have one edge cut to the curvature specified for the crown of the pa
ment, and have a thickness equal to the width of the joint as above specif
When for use in longitudinal joints in concrete pavements adjacent
curbs, gutters, headers, etc., molded joints shall be made in the lengths
widths ordered.

The various grades of bitumen used for the fabrication of expansion j
fillers shall comply with the requirements given below.

Grades	M. A.		P. A.		P. T.	
Tests	Min.	Max.	Min.	Max.	Min.	M
1. Specific gravity at 25°C.	1.00	...	1.00	...	1.22	1
2. Penetration at 25°C.–100 g. for 5 sec.	25	35	30	40		
3. Penetration at 46°C.–100 g. for 5 sec.	...	55	...	70		
4. Melting point (ball and ring)°C	...	...	65	95	36	
5. Evaporation loss on 20 g. at 163°C. for 5 hours, per cent	...	1.0	...	1.0		
6. Solubility in benzol, C_6H_6, per cent	99.0	...	99.5	...	65.0	80
7. Solubility in carbon tetrachloride, CCL_4, per cent	...	...	99.0			
8. Flash point in °C.	...	...	200			
9. Ductility at 25°C., centimeters	4.0	...	4.0			
10. Float Test at 100°C.	...	...	...	...	55	
11. Distillation 0°–170°C., per cent	...	...	...	...	...	
Distillation 0°–300°C., per cent	...	...	...	...	...	5
12. Free carbon, per cent	...	...	...	...	20.0	35

104. Lignin Binders

They must be concentrated liquid extracts from organic matter, unif
in composition; homogeneous, free from mineral oils, asphalts or tars. I
ing concentration the liquors must not be heated above 212°F. They n
conform to the following requirements:

Grades	G. N.	
Tests	Min.	Ma
1. Specific gravity at 60°F.	1.25	
2. Solubility in cold water, per cent	99.5	
3. Solubility in hot water, per cent	99.5	
4. Evaporation loss at 100°C. to constant weight, per cent	.....	55.
5. Ash content, per cent	.....	9.
6. Free acids, per cent	.....	0.
7. SO_3 content as sulphite, per cent	.....	1.
8. CaO content	.....	2.
9. MgO content, per cent	1.25	
10. Ferric oxide content, per cent	.....	0.

105. Inorganic Binders

is class of binder shall consist of concentrated solutions of soluble alka- silicates and may contain soluble organic compounds. They shall l the following requirements:

Grades	S. S.		R. M.			
Tests	Min.	Max.	Min.	Max.	Min.	Max.
Solubility in hot water, per cent.	99.0	.....	99.5			
Specific gravity at 60°F........	1.35	1.40	1.20	1.30		
Residue on evaporation at 110°C. to constant weight, per cent....................	60.0	70.0	30.0	40.0		
Silica content of residue, per cent	70.0	80.0	36.0	40.0		

106. Telford Base Stone

is stone shall be prepared from a hard, durable rock, such as trap, te, gneiss, limestone, etc. In the selection of these stones no decom- l, weathered, shattered or soft stone shall be included. The stone be broken nearly rectangular in shape, and of such a width that, after ping, they will produce a foundation of the required thickness. When ecial size is specified the stone shall be so broken that, after knapping rimming up, they will be approximately eight (8) inches in depth, not an two (2) or more than (5) inches in width, and from six (6) to twelve nches in length.

107. Cobble Stones

bble stones shall be composed of only good, hard, durable stone which early uniform in size. They shall not exceed five (5) inches in their st diameter, except for the center line and side lines of gutters where n stones may be used. They must have fairly smooth, even faces that ermit the construction of a gutter surface with a uniform contour.

108. Rubble Stones

bble stones shall be prepared from a hard, durable, tough stone, such up, granite, gneiss, etc., that has a fairly uniform fine grain, is sound, rom weathered or deomposed stone, shattered ends or structural defects, ed laminations, seams or cracks, and must be approved by the engineer e use intended.

hen for use in a rubble gutter stone shall be not less than six (6) nor more eight (8) inches in depth, not less than two (2) nor more than five (5) s in width, and from six (6) to ten (10) inches in length. The top e must be approximately flat, and so cut as to permit the construction utter surface of the proper contour. When for use in rubble masonry s otherwise specified the stone for the faces of the wall shall be not han six (6) inches thick nor less than twelve (12) inches long. The shall not be less than the thickness and the length shall not exceed (3) times the thickness. Selected stones, rough squared, cut to the ed pitch, shall be prepared for use at all angles and ends of walls.

109. Stone Block for Gutters

ne block for gutters shall be prepared from a hard, tough rock such as granite, gneiss, etc. In the selection of the stone all decomposed, ered, soft, brittle or laminated stone will be excluded. The blocks l be of nearly the same degree of hardness and toughness. They shall cut that they will be practically rectangular in shape, be not less than) nor more than eight (8) inches square on top, and from six (6) to (8) inches in depth. The blocks shall be so split and dressed as to when laid, close joints not exceeding one-half (½) inch in width on the nd have a fairly smooth top and bottom surface.

110. Construction Brick

Brick for use in constructing manholes, catch basins, etc., shall be whole building brick of a standard brand or make. They must be uniform commercial size.

The physical properties of construction brick shall comply with the req ments for Hard Brick, as defined in A. S. T. M. standards, Serial Designa C21-20.

111. Masonry Stone

The stone used in the construction of stone masonry, such as retai walls, headers, etc., shall be a hard, durable stone, that will easily pe of its being cut, chipped or chiseled into the required shape or form. S shall be of two grades, rough dressed and hand dressed. Rough-dre stone shall be fairly rectangular in shape, have at least one smooth face, be not less than three (3) inches in thickness, nor less than eigh inches in width, and have a length greater than one-half the thickness o wall in which the stone will be used. Hand-dressed stone will be dressed to nearly rectangular shape. The front face shall be smooth even, free from objectionable depressions or projections, be rectan in shape, have straight edges with square corners, and the other faces dr nearly perpendicular to this face.

Hand-dressed stone shall be not less than eighteen (18) inches in le six (6) inches in thickness, nor less than one (1) foot in width, and mu approved by the engineer before being used.

Header stone shall be equal in length to the thickness of the wall in v it will be used.

112. Stone Curbing

Straight curbing shall be made from either granite or bluestone; cir curbing from granite only.

The granite used shall be a good grade of medium fine grain gr which has a uniform texture and distribution of its constituent miner neither stratified nor laminated, and is free from seams, evidence of wea ing, or disintegration.

The bluestone shall be a hard, durable stone that is free from such imp tions as soft or weathered spots, shattered layers, weathered bedding p or distinct lines of stratification. It must be of sufficient hardness as serviceable, but not so hard as to be brittle or glassy.

All curbing shall be cut in lengths of not less than four (4) nor more eight (8) feet, and be twenty (20) inches in depth unless a concrete fo is specified to be used, when the depth shall be sixteen (16) inches.

The top of all curbing shall be dressed to an even, smooth surface fc length, have straight, even edges, and a one-quarter (¼) inch bevel. front faces shall be hand dressed full length for a depth of twelve inches, and have a batter of one (1) inch from the top of the curb t finished line of the gutter and be straight from this line to the bo The back face shall be hand dressed for a depth of three (3) inches. dressed faces shall be free from depressions, projections or other de and hand dressed in a manner equal to four (4) cut stone finish. All cu shall have square ends that will permit joints being made not more one-quarter (¼) inch in width for full depth.

112A. Five-inch Curbing.—Five-inch curbing shall be five (5) inch thickness on the top and not less than six (6) nor more than eight (8) i in thickness on the bottom; other dimensions to be as above specified.

112B. Six-inch Curbing.—Six-inch curbing shall be six (6) inch thickness on the top and less than seven (7) nor more than eight (8) i in thickness on the bottom; other dimensions to be as above specified.

112C. Eight-inch Curbing.—Eight-inch curbing shall be not less eight (8) inches in thickness on the top nor less than nine (9) nor more eleven (11) inches on the bottom; other dimensions to be as above specifi

112D. Circular Curbing.—Circular curbing shall be similarly cut dressed in the same manner as straight curbing. It must be so cut conform accurately to the required radius. The ends shall be so cut permit of joints being made of not more than one-quarter (¼) inch in for full depth.

113. Paving Blocks

113A. New Granite Paving Blocks.—New granite paving blocks sh prepared from a granite of medium or fine-grained structure, showi

distribution of the constituent minerals of uniform quality, structure
exture.

ysical Properties.—The granite shall have a French coefficient of wear t less than nine (9). The average of three determinations shall be used porting this test.

mensions.—The blocks shall meet the following requirements:

Length on top	8 to 12 in.
Width on top	$3\frac{1}{2}$ to $4\frac{1}{2}$ in.
Depth	$4\frac{3}{4}$ to $5\frac{1}{4}$ in.

essing.—The blocks shall be so dressed that the faces will be approxily rectangular in shape and the ends and sides sufficiently smooth to it the blocks to be laid with joints not exceeding one-half ($\frac{1}{2}$) inch in at the top and for a distance of one (1) inch down therefrom, and not d one (1) inch in width at any other part of the joint. The top surface e block shall be so cut that there will be no depressions measuring than three-eighths ($\frac{3}{8}$) inch in depth from a straightedge laid in any ion on the top of said block and parallel to the general surface there of. re shall be exercised in handling the blocks so that the edges and corshall not be chipped or broken. Blocks otherwise acceptable may be ed on account of spalling.

pection.—The engineer or his authorized representative shall select work not less than three (3) blocks which fairly represent the actual ent. These blocks shall be tested for the French coefficient of wear. samples shall include blocks that would be rejected by visual examina- The bedding plane shall be marked on at least two (2) of the blocks ed. All deliveries shall be subject to further inspection at the work to and during paving. Blocks received at the work that are manured at a quarry other than the quarry or quarries stated in the certificate itted by the contractor at the time of bidding shall be rejected.

B. Recut Granite Paving Blocks.—The recut granite paving blocks be made from the blocks in the street or roadway which is to be paved. ional blocks required shall be either new granite blocks or made from used granite blocks of the proper size and equal in quality to those in avement to be repaved.

ysical Properties.—All recut blocks must show a French coefficient of equal to that specified herein for new granite paving blocks.

mensions.—The blocks shall meet the following requirements:

Length on top	Not less than 6 in.
Width	$3\frac{1}{2}$ to $4\frac{1}{2}$ in.
Depth	$4\frac{3}{4}$ to $5\frac{1}{4}$ in.

essing.—The blocks shall be so dressed that the faces will be approxiy rectangular in shape and the ends and sides sufficiently smooth to it the blocks to be laid with joints not exceeding one-half ($\frac{1}{2}$) inch in at any part of the joint. Blocks less than six and one-half ($6\frac{1}{2}$) s in length shall be reclipped. The head of the blocks shall be so cut hey shall have not more than three-eighths ($\frac{3}{8}$) inch depression across ead measured from a straightedge held parallel to the general surface blocks.

pection.—After the blocks have been recut they shall be carefully cted. Undersized or irregular-shaped blocks or those not complying the above requirements shall be rejected and must be removed from the vay.

C. New Sandstone Paving Blocks.—Sandstone paving blocks shall st of the best quality sandstone, free from quarry checks or cracks, and be quarried from fine grain live rock, showing a straight and even ire. The material shall be of uniform quality and texture, free from s, lines or clay, or other substances which, in the opinion of the engineer, e injurious to its use as paving blocks.

ysical Properties.—All sandstone blocks must have a French coefficient ar of not less than nine (9). The average of three (3) determinations be made in reporting this test.

nensions.—The blocks shall meet the following requirements:

Length on top	8 to 12 in.
Width on top	$3\frac{1}{2}$ to $4\frac{1}{2}$ in.
Depth	$4\frac{3}{4}$ to $5\frac{1}{4}$ in.

Dressing.—The blocks shall be dressed in the same manner as that spe for new granite paving block.

Inspection.—The same method of inspection shall be used as that spe for the new granite paving blocks.

113D. Durax Paving Blocks.—Durax paving blocks shall be cut fr granite that complies with the requirements specified herein for new gr paving blocks.

Dimensions.—Durax blocks shall have six (6) irregular, approxim square surfaces, the edges of which shall measure not less than two and t quarter ($2\frac{3}{4}$) inches, nor more than four (4) inches.

Dressing.—The blocks shall be dressed so as to conform with the rec ments specified for new granite blocks, except that the faces shall be s instead of rectangular.

Inspection.—The same method of inspection shall be used for I blocks as that specified for new granite blocks.

113E. Vitrified Paving Brick.—All brick used for pavement or g surfaces shall be vitrified and prepared especially for paving pur They shall be pressed brick with lugs or wire-cut lug brick when the pave is to be Portland cement grout filled, and wire cut without lugs whe pavement is to be filled with a bituminous cement or bituminous m Special forms shall be furnished when so ordered or required witnout compensation.

All brick shall be thoroughly annealed, tough, and durable, regular i and shape, and evenly burned. When broken, the brick shall show a c stonelike body free from lime, air pockets, cracks, or marked lamina Kiln marks shall not exceed three-sixteenth ($\frac{3}{16}$) inch, and the we surface shall show but slight kiln marks.

Representative samples of the brick shall meet the following requirer when subjected to the rattler test:

Average loss by abrasion on 3-in. wire-cut brick twenty-five (25) per maximum, wenty-seven (27) per cent.

Average loss by abrasion on $3\frac{1}{2}$-in. wire-cut brick, twenty-three (23 cent; maximum, twenty-five (25) per cent.

An abrasion loss of one (1) per cent lower than that specified abov be required for repressed paving brick.

A maximum of three tests may be used as a basis for rejection.

The brick shall meet the following dimensions;

Either $8\frac{1}{2} \times 3 \times 4$ in., or $8\frac{1}{2} \times 3\frac{1}{2} \times 4$ in.

Variations among brick from a single plant shall not exceed the foll limits:

Variation in length	$\frac{1}{2}$ inch
Variation in width	$\frac{1}{8}$ inch
Variation in depth	$\frac{1}{8}$ inch

If the edges of the brick are rounded, the radius shall not exceed sixteenth ($\frac{3}{16}$) inch.

The name or trade-mark of the manufacturer, if shown on the brick be recessed and not raised.

The brick shall be subjected to inspection subsequent to deliver during laying in order to cull out and reject upon variations from the g and dimensions clauses and upon the following grounds:

All brick which are broken through or chipped in such manner neither wearing surface remains substantially intact, or in such m that the lower or bearing surface is reduced in area by more than one-e ($\frac{1}{8}$).

All brick which are cracked to a depth greater than one-eight ($\frac{1}{8}$ on any surface, or which are cracked on the wearing surface.

All brick which are so offsized or misshaped, bent, twisted, or kiln m that they will not form a proper surface or align properly with other br

All brick which are obviously too soft and too poorly vitrified to e street wear.

113F. Asphalt Blocks.—These blocks shall be prepared from trap roc a mineral filler of ground limestone or Portland cement bound tog with an asphaltic cement. The trap rock shall be prepared by recru clean $\frac{3}{4}$-in. to $1\frac{1}{2}$-in. stone which is free from all weathered or decom material and quarry screenings. The product thus produced must al through a screen having circular openings one-quarter ($\frac{1}{4}$) inch in diar the stone therein shall be as near cubical as possible, and be so graded

uce in the finished block, the mesh composition specified below. The ral filler must fulfill the requirements given in Article 97; the asphalt ent, those for Grade NA.[5], as defined in Article 99*A*.

l blocks shall be uniform in texture and composition, straight, true to , free from warp, wind, and broken corners or edges. The planes of the site faces and edges must be parallel. Each block shall be five (5) es in width, twelve (12) inches in length, and two (2) inches in depth and variation therefrom of over one-quarter (¼) inch in length or one-eighth inch in width or depth from these dimensions will cause the rejection ch blocks.

nchor blocks shall, in addition to meeting the requirements specified nabove, have a strip of sheet iron one (1) inch wide so embedded in the k that it is firmly held in place, does not project less than three-eighths inch or over one-half (½) inch below the surface of the face of the block, iptical in shape, the major axis of which is not less than nine (9) inches ver ten (10) inches and the minor axis not less than two and one-half) inches or over three (3) inches.

l blocks must have a specific gravity at 15.5°C., of not less than 2.40 and prepared that they will comply in all respects to the following additional irements:

COMPOSITION

Size of screen and sieves		Minimum, %	Maximum, %
Passing	Retained on		
....	¼-in. screen	....	0.0
¼-in. screen	20-mesh	35.0	50.0
20-mesh	100-mesh	15.0	30.0
100-mesh	....	26.0	36.0
umen content	....	6.5	8.0

ter having been dried for twenty-four (24) hours at a temperature of F., the blocks shall not absorb more than one (1) per cent of water d on the weight after drying, when immersed in water for seven (7) days. ne average penetration of the block under the punch test shall not exceed in. at 100°F., and 1.00 in. at 115°F.

ocks which have the corners or edges broken off of one end only and will the other requirements giving hereinabove, may be used for half blocks cent to curb, for breaking courses, and in making closures.

addition to the above requirements, the block must be prepared by a ufacturer or producer who is experienced in the preparation of such ks. Before approval by the engineer of any blocks of this type, the ufacturer or producer thereof must submit a statement giving the loca- of two or more pavements that are five (5) years or more old, have n good service during this time, do not show evidence of an unnatural or deterioration, and were constructed of paving blocks of the type n specified.

ch consignment or carload shall be sampled in such a manner that each ple represents about ten thousand (10,000) blocks. The blocks selected he samples shall be taken at random from the shipment and shall repre- the average quality of blocks contained in the consignment. In case blocks fail to pass the tests herein specified, a check analysis shall be e on another sample similarly selected. If the check sample passes the irements above specified, the shipment or consignment shall be accepted, rwise rejected, unless the engineer shall agree to resample the gnment.

3G. **Wooden Blocks.**—All wooden blocks used for paving purposes be creosoted in the manner designed below, and comply with the other rements given.

ality of Wood for Blocks.—The lumber to be used in manufacturing ks shall be Southern yellow pine, Norway pine, Douglas fir, tamarack, gum, or hemlock, but only one kind shall be used on any one section vement.

The blocks shall be sound and shall be well manufactured, square but square edged, free from unsound, loose, or hollow knots, knot holes, w holes, and other defects such as shakes, checks, etc., which would be injur to the blocks.

The number of annual rings in the one (1) inch measured radially, w begins two (2) inches from the pith of the block, shall not be less thar (6), provided, however, that blocks containing between five (5) and six rings in this inch will be accepted if they contain thirty-three and one-t (33⅓) per cent or more of summer wood. In case the block does not con the pith, the one (1) inch to be used shall begin one (1) inch from the which has the shortest radius. When being treated the blocks in charge shall contain an average of at least seventy (70) per cent of h wood. No one block shall be accepted that contains less than fifty per cent of heart wood.

Size of Block.—Blocks shall be from five (5) to ten (10) inches in ler but shall have an average length of twice the depth; they may be from t (3) to four (4) inches in width, and three (3), three and one-half (3½ four (4) inches in depth, as specified. Only block of a single width sha used in a section of pavement. A variation of one-sixteenth (1/16) of an shall be allowed in the depth, and one-eighth (⅛) inch in the w of the block.

Properties of Preservatives.—The preservative to be used in manufact of block shall be a coal-tar distillate or a coal-tar paving oil, complying the requirements given therefor. The preservatives used shall be design by the engineer, but only one preservative shall be used on any one cont

Inspection of Preservative.—The manufacturer of the blocks shall pe complete sampling at all times and places, and shall furnish, if requ satisfactory proof of the origin of the preservative. Samples of the prese tive, taken from the treating tank during treatment, at no time shall an accumulation of more than two (2) per cent of sawdust, dirt, or foreign materials. Due allowance shall be made for such accumulati foreign materials by injecting an additional quantity of preservative int blocks.

Treatment of Blocks.—The blocks shall be treated with the preserv under pressure so that they shall contain not less than sixteen (16) po per cubic foot, and at no time shall be subjected to a temperature of than two hundred and forty (240) degrees Fahrenheit. They shall satisfactory penetration of the preservative after treatment. All b which have become warped, checked or otherwise injured in the proce treatment will be rejected.

Inspection of Blocks.—The blocks will be subjected to inspection be during and after treatment and may be reinspected at any time. The shall be equipped with gages and appliances necessary for suitable inspe and every facility for this inspection shall be afforded.

Handling of Blocks.—The blocks at all times shall be kept clean, neatly and shall be handled carefully, as blocks otherwise acceptable m rejected if they become coated with dirt.

114. Pipes

All pipe of any given type, grade, or size must be uniform in appear composition, and texture. The smallest inside diameter shall be the go ing size. Unless otherwise specified, all lengths must be straight, tr form, with circular cross-sections, and free from cracks, holes, ragged c or broken ends. No culls, second grade, used or second-hand, injur defective pipe shall be used, or other grades or sizes substituted for specified. No pipe shall be used until approved by the engineer. Wher possible, the manufacturer should have consignments inspected and appr before shipment.

114A. Drain Tile.—The pipe used for drain tile shall be either vit tile or machine-made concrete pipe, unless otherwise shown on plans.

Vitrified pipe shall be of the best-grade, first-quality, salt-glazed pi the hub-and-spigot type. The grazing shall extend uniformly over bot exterior and interior surfaces. It shall be uniformly and thoroughly bu free from blisters, cracks, or other defects that will injure it for the pu intended. The dry pipe must give a clear, metallic ring when ta It shall be furnished in lengths of not less than twenty-four (24) in The inside diameter shall be the determining size. Unless otherwise s fied, all lengths must be straight. When required, curved or special for pipe shall be furnished.

ncrete drain pipe shall be made of the same materials and in the manner fied for machine-made reinforced concrete pipe, given below, with the otion that no reinforcing metal is required and the ultimate strength of shall be 1000 D. The dimensions for this kind of pipe shall conform e A. S. T. M. requirements, Serial Designation C14-21.

4B. **Cast-iron Pipe.**—All cast-iron pipe shall be of the hub-and-spigot . It shall be manufactured in the lengths specified. When no length esignated, it shall be manufactured, in lengths not less than three (3) nor more than twelve (12) feet. Unless otherwise specified, each length have square ends, be straight in the direction of the cylinder and the and outer surfaces shall be concentric and true circles in cross-section. ipe shall be smooth, free from scales, lumps, blisters, cracks, broken ends, her defects considered injurious for the use intended. Small sand- or -holes will not be considered defects. Each joint shall have the maker's ls cast upon it in raised letters.

cast-iron pipe shall be made from first quality cast iron which is free clinker iron or other inferior iron. It must produce a sound, tough, ole casting, having a uniform, even grain that is soft enough to admit actorily of drilling and cutting.

her cast-iron water pipe, Grade A, or cast-iron culvert pipe will be ted provided it complies with the requirements given above and its it per lineal foot is not less than that given below for the different sizes.

minal inside diameter, inches	Thickness, inches	Weight per lineal foot, pound
4	0.42	20.0
6	0.44	30.8
8	0.46	42.9
10	0.50	57.1
12	0.54	72.5
14	0.57	89.6
16	0.60	108.3
18	0.64	129.2
20	0.67	150.0
24	0.76	204.2
30	0.88	291.7
36	0.99	391.7

pipe will be accepted, the weight of which shall be five (5) per cent nan the weights herein specified.

ch section of cast-iron pipe shall be coated inside and outside with coal-tch varnish to which sufficient linseed oil has been added to make a h coat, tough and tenacious when cold, with no tendency to scale off.

1C. **Corrugated Sheet Iron or Steel.** *Size and Shape.*—Each joint have square ends, be circular in form and of the size and length indi- on plans. When no particular length of joint is indicated, the pipe be shipped in standard lengths of the required size. The inlet and ends shall be reinforced by a round rod not less than one-half (½) n diameter. Sufficient metal shall be lapped over this rod to cover it letely. Each joint shall be firmly and neatly riveted together, the being spaced not over three (3) inches apart in longitudinal seams, nore than eight (8) inches apart in circumferential seams. The metal be lapped not less than one and one-half (1½) inches in longitudinal nor less than one (1) corrugation in circumferential seams.

nposition of Materials Used.—All corrugated pipe shall be manu- ed from galvanized sheets of iron or steel that were prepared from a pure-iron or a copper-bearing pure-iron steel. These sheets must niform in thickness, and free from blisters, scales, or other defects will injure them for galvanizing. All rivets, reinforcing rods, and ngs or connecting bands shall be made from the same grade metal as ody of the pipe.

e iron shall be so refined that it shall have an iron content of not less ninety-nine and seventy-nine hundredths (99.79) per cent, copper- ng pure iron, not less than 99.75 per cent and not less than 0.20 per

cent of copper. Copper steel shall be so prepared that it shall contai less than three-tenths (0.3) of one (1) per cent of copper nor more fifteen hundredths (0.15) per cent of carbon, five hundredths (0.05) cent of sulphur, four hundredths (0.04) per cent phosphorus, and thirty hundreths (0.30) to forty-five hundredths (0.45) per cent mangai

Galvanizing.—All sheet metal used in the manufacture of corru pipe shall be galvanized on both sides by the hot-dipping process. square foot of uncorrugated sheet shall contain not less than two (2) o of spelter, evenly distributed over both surfaces. The zinc coating mu uniform in thickness, completely cover both sides, firmly adhere th and be free from imperfections of any kind, and show no signs of crack blistering. All rivets, reinforcing rods, and couplings or connecting b shall be galvanized in the same manner as the sheets.

Corrugation.—The corrugations of any one given size of pipe sha uniform but must not be less than three-eighths (3/8) inch in depth more than three (3) inches from center to center.

Gages of Sheets Required.—Corrugated metal pipe shall be made of s of the following thickness (U. S. Standard Gage Measure):

Diameter	Gage
Pipe from 12 to 20 in. shall not be lighter than	16
Pipe from 24 to 30 in. shall not be lighter than	15
Pipe from 36 to 42 in. shall not be lighter than	14
Pipe from 48 to 60 in. shall not be lighter than	12

114D. Reinforced Concrete Pipe. *Type of Pipe.*—Reinforced con pipe may be either cast or machine made. Each type shall confor size, shape and reinforcement to the standards as shown in the table for a part in these specifications. The letter C or M shall be plainly impr upon the outside surface of each length of pipe to designate whether cast or machine-made respectively. Each length of pipe shall als clearly marked with the date of manufacture and the name or trade- of the manufacturer.

Shape.—All concrete pipe 12 in. or over in diameter shall be reinforc herein specified and be of the bell-and-spigot type unless some other t specified or shown on the plan. Each section shall have square end circular or elliptical in cross-section, unless otherwise specified, and walls of uniform thickness throughout except the bell end, which have a thickness of not less than three-fourths (3/4) of the wall thicknes point 1/4 in. from the end of the bell.

Size.—It shall be cast in sections, the length of which shall be as h specified or shown on plans. When no particular length is specified pipes shall be manufactured in standard lengths of not less than fou feet, nor more than six (6) feet. The smallest inside diameter shall g in deciding the sizes of any given pipe.

Joints.—The bell end shall be so constructed that the spigot end enter to full depth. The distance the spigot end must enter freely sh as follows: 12- to 18-in. pipes not less than two and one-half (2½) in 18- to 30-in. pipe, not less than three (3) inches; and 30- to 72-in. pip less than three and one-half (3½) inches.

Finish.—The surface of all pipe, both interior and exterior shall be sn and even, of uniform texture, free from surface checks, cracks, bli fractures, laminations, lean and porous spots. The pipe shall be tr dimensions intended in the design with a permissible variation fron true form of not more than 1½ per cent. The shell of the pipe ma thicker than called for in the designs, but it shall not be less than the c nated shell thickness by more than 5 per cent.

Composition.—Concrete pipe shall be prepared from a concrete m having the following composition:

Portland cement....................	1 part by volume
Fine aggregate......................	1 to 2 parts by volume
Coarse aggregate....................	3 parts by volume

and sufficient reinforcing metal to meet the requirements given below.

Materials.—The Portland cement shall comply with the requirer give in Article 96. The fine aggregate shall be concrete sand, comp with the requirements given in Article 95-B. The coarse aggregate be dustless screenings prepared from trap rock, dolomite or pea grav defined in Articles 92 and 94 respectively.

e reinforcing metal shall be woven wire mesh, expanded metal, rods, s, or spirals manufactured from billet steel which complies with the rements specified therefor by the A. S. T. M. Standards, Serial Design A 15-14. It must be free from grease, dirt, rust, or any foreign rial that will prevent the concrete from properly adhering thereto.

paration.—Concrete pipe shall be prepared from the materials above fied. Each length shall be cast in a single operation. The molds be properly assembled, cleaned, and oiled when so ordered before any rete mortar is placed therein. The reinforcing metal must be so held e required position that it will not be displaced during manufacture e pipe. For cast pipe the forms shall not be removed until the con- is at least twelve (12) hours old, and after removal unless steam cured, pipe must be covered and be kept wet at least ten (10) days. Pipe ıfactured when the atmospheric temperature may drop below 35°F. be so protected that the concrete threin will not at any time have a erature below 35°F., until the concrete is at least seven (7) days old. shall not be shipped for use that is less than fourteen (14) days old.

inforcement.—All pipe shall be reinforced as herein specified. Pipe r thirty (30) inches in diameter shall have a single line of reinforcement, 7 (30) inches and above, two lines of reinforcements as shown in the below or an approved method of reinforcement developing equivalent gth.

gle lines of reinforcement shall be placed at equal distances from the and outside surfaces of the pipe.

uble lines of reinforcement shall be placed parallel to each other and 1) inch from the inside and outside surface walls of the pipe, other rements to be as above defined for single-line reinforcements.

ıgitudinal reinforcement shall extend full length of each section and the bell, and shall be wired or otherwise securely fastened to the body bell reinforcement.

cular reinforcement shall extend completely around the pipe and have ent lap not less than forty (40) diameters of the circular reinforcement be firmly fastened together.

e thickness of the pipe walls and total cross-sectional area of circular ongitudinal reinforcement for the different sizes of the pipe shall be ess than those shown in the table given below:

ım-er pipe, hes	Cast pipe		Machine-made pipe		Longitudinal reinforcing	
	Shell thickness, inches	Minimum area of circular reinforcing per foot of pipe	Shell thickness, inches	Minimum area of circular reinforcing per foot of pipe	Minimum number of long	Minimum total area long
2	2	0.070	1½	0.093	4	0.196
5	2¼	0.096	1¾	0.123	4	0.196
8	2½	0.123	2	0.160	4	0.1 6
4	3	0.180	2½	0.220	4	0.196
0	3½	2 × 0.167	3	2 × 0.210	8	0.392
6	4	2 × 0.200	3	2 × 0.300	8	0.614
2	4½	2 × 0.230	3½	2 × 0.320	8	0.614
8	5	2 × 0.265	4	2 × 0.350	8	1.200
4	5½	2 × 0.300	4½	2 × 0.390	12	1.326
0	6	2 × 0.330	5	2 × 0.410	12	1.326

ength.—When supported at the bottom upon a knife edge one (1) inch dth, or upon two rounded bearings centered two (2) inches apart, in manner than an even bearing is provided throughout the whole length, sive of the bell, and load is applied at the crown through a similar edge, all pipe twenty-four (24) inches in diameter and greater shall tand, without the appearance of a visible crack extending through the length of the pipe, a load of 1000 D lb. per lineal foot of laying length;

all pipe of a diameter less than 24 in. when tested in a similar manner withstand a load of 1330 lb., as specified for larger size pipe. When t to destruction, all pipe of twenty-four (24) inches diameter and greater show an ultimate strength of not less than 1500 D lb. per lineal fo laying length; all pipe of a diameter less than twenty-four (24) inches in a similar manner, show an ultimate strength of not less than 2000 per lineal foot of laying length. In the above expression of load D i inside diameter of the pipe in feet.

Absorption.—The maximum average absorption as obtained by A. S. T. M. standard boiling test shall not exceed eight (8) per cent by we

Testing.—Each manufacturer furnishing pipe under these specifica shall be fully equipped to carry out the tests herein designated. Upo demand of the department and under its supervision, the manufac shall perform such number of tests as the department may deem nece to establish the quality of the pipe offered for its use. Failure of any of pipe to meet the test requirements shall be sufficient cause for reje of all pipes of that size, which the test specimen represents.

Inspection.—All pipes shall be subject to inspection at the factor point of delivery, by a competent inspector employed by the depart The purposes of the inspection shall be to cull and reject pipes which, pendent of the physical tests herein specified, fail to meet the requirer of these specifications and rejection through inspection may be mad account of any of the following:

(*a*) Porous spots on either inside or outside surface of pipe havir area of more than ten (10) square inches and a depth of more than half inch.

(*b*) Pipes which have been patched to repair porous spots, cracks or defects.

(*c*) Variations in any dimension exceeding the permissible variations

(*d*) Fractures or cracks passing through the body or bell, except t single crack at either end of pipe not exceeding three inches in lengt single fracture in the bell not exceeding two inches in depth nor extending than 10 per cent around the circumference of the bell will not be consi cause for rejection.

(*e*) Failure to give a clear ringing sound when tapped with a light har

(*f*) Exposure of the reinforcement when such exposure would in that the reinforcement was misplaced.

(*g*) In machine-made pipe the entire absence from the exterior su of a pipe of the characteristic water marks due to suction, caused b removal of the outer form, shall be considered proof of an insufficient tity of mixing water and shall be sufficient cause for rejection of such

Vitrified Pipe

Vitrified pipe shall be double-strength, salt-glazed, vitrified, ston sewer pipe of the first quality (for dimensions and weights, see p. The item will include the furnishing delivering, handling, laying, and ce ing of joints; also the operations of excavating the trench, bracing, she or otherwise supporting the sides, grading and preparing the bottom, filling and compacting to the original surface, and the removal of all su material.

115. Reinforcing Metal

All reinforcing metal shall be made from open-hearth or Bessemer complying with the A. S. T. M. standard requirements of tentative s ards for the type of steel from which the reinforcing metal is required made.

When any special design, shape, or form of reinforcing metal is spe to be used, the same shall be used in the manner and in the quantity requ All reinforcement shall be placed as shown or as otherwise ordered b engineer. It must be free from rust, paints, oils, grease, or other fo materials that will prevent the proper bond being secured betweer concrete and the metal. All reinforcement must be straight unless cu or special shapes are required. When so required, they must have designated shape when used.

When reinforcing bars or rods have to be spliced, the lap shall be less than forty (40) diameters for deformed rods, or fifty (50) diamete plain rods. The lapped ends shall be firmly clamped together or o wise securely fastened in a manner satisfactory to the engineer. All or rods shall be firmly and securely fastened together in a satisfactory

t all intersections. At intersections the members in reinforcing fabric be welded or otherwise securely fastened.

116. Structural Steel

ructural steel shall be prepared from a steel that complies with the rements given in Volume 16, Part 1 of the A. S. T. M., pages 99 and o 113. A coupon giving the analysis of the Melt Number from which teel forms or structures were made shall be furnished with each shipment. henever any special forms or shapes are specified to be used, the steel be made to conform to such shapes and dimensions. The methods in manufacturing the steel into the forms required shall be such that teel is not injured thereby. All shearing and chipping shall be neatly accurately done, and all portions of the steel which will be exposed ew must be neatly finished. All holes must be neatly punched and ing and bolting performed in a workmanlike manner. Undersized shall be reamed to size. All pins and rivets must be full size and fit ately at normal temperature.

structural steel must be protected from the weather and have clean ces before being worked into the proper shapes or forms. When tures are required to be painted before shipment, the surfaces must be ed and given a coat of an approved paint.

117. Miscellaneous Iron and Steel

cast-iron, malleable-iron, or cast-steel castings shall be prepared in nanner and from a metal which complies with the A. S. T. M. requires as defined in the 1918 Year Book, pages 406, 403, and 220 respectively. nen any special size, shape, or form is specified to be used, the castnust comply with these dimensions. All castings must have the weight thickness of metal as specified or shown on plans. They must be y finished, free from fins, broken edges, blow-holes, cracked sections, arped surfaces. They must be properly protected during shipment painted when so specified.

118. Guard Rails

ard rails shall be made either of wood or galvanized pipe as specified. dimensions or sizes of materials to be used therefor shall be as specified. n no definite size or character of material as specified for a given type of l rail, the material furnished shall comply with the requirements n below for such materials.

8A. **Wooden Guard Rails.**—The lumber used in all wooden guard rails be well seasoned, straight grained, sound, surfaced on all sides and ee from shattered or cracked ends, barked edges, loose or unsound s, and reasonably free from other knots.

e wooden rails shall be made from long-leaf yellow pine, chestnut, or The top rails or caps shall be two-inch plank, eight (8) inches wide, six- (16) feet long. The bottom rail shall be two-inch plank ten (10) inches , and sixteen (16) feet long. All rail plank must have square ends for ull width of the plank. Rails and caps shall have their joints on alterposts.

sts shall be made from chestnut, oak, locust, white or red cedar. They not be less than seven (7) feet in length, six (6) inches square, have op ends cut to the bevel required, the lower end off square, and the r four (4) feet treated. The treatment shall consist of immersing the in a bath of hot tar. The tar used for this purpose shall be Grade U^2, as defined in Articles 100A and 100B. The tar shall be heated een 225 and 275°F., and kept at this temperature during the treatment e posts.

e posts shall be placed in a vertical position in the hot tar for not less thirty (30) minutes, or as much longer as is needed to heat the lower (4) feet of the posts to the same temperature as the tar. Immediately removing from the hot tar, it shall be immersed in a bath of cold f the same grade until cooled to normal temperature. The portion of posts treated shall be slightly in excess of the depth that the posts will aced in the ground, but in no case shall the treatment extend more than 5) inches above the ground.

8B. **Galvanized Pipe Rails.**—All pipe shall be made from the best e of galvanized wrought-iron pipe that is equal in every respect to the grade of "Byers' wrought-iron galvanized pipe." All such pipe must an even, smooth surface, be full weight and thickness, well threaded,

and free from rust or cracks. All fittings used in pipe guard railing, be galvanized and made from malleable iron that is free from flaws, cr etc. They shall be neatly threaded or bored to the required size ne for the proper installation of the pipe.

Steel Cable

Cable shall be three-strand, seven wire to the strand, double-galvar steel-wire cable of ¾″ diameter. Individual wires shall be not less 0.120″ diameter.

The minimum tensile strength of the rope shall be 15,000 lb.

Each wire of the cable and all fittings and fastenings, except thre portions, shall be galvanized by the "hot dip method" and shall ha continuous coating of pure zinc of a uniform thickness, so applied that i adhere firmly to the surface of the wire, and it shall be capable of withs ing four immersions in a standard testing solution of copper sulphate wi showing any trace of metallic copper on the steel. The first three immer shall be for a period of 1 min. each and the fourth immersion for a per ½ min.

The threaded portions of all fittings and fastenings shall have a conti coating of pure zinc of a uniform thickness, so applied that it will a firmly to the surface of the thread, and it shall be capable of withstandin immersions, of 1 min. each, in a standard testing solution of copper sul without showing any trace of metallic copper on the steel.

These threaded portions shall receive, after erection, two coats of alum paint meeting the requirements under Materials of Construction.

119. Timber and Lumber

General.—All timber or lumber shall be well seasoned, straight gra sound, free from loose knots, worm holes, shattered or cracked ends, b edges, or other defects that impair its strength or durability for th intended. It must be cut or sawed to the specified size and dimen and when painting is required, must be surfaced on all faces to be pa It must be of sufficient length to give square ends for full width of the l specified.

When a special kind or grade of timber or lumber is specified, this or grade must be furnished. When no kind or grade is specified, the may be white oak, chestnut, long leaf yellow pine. Timber for u piling must withstand the specified driving without spreading or brooming of the head. It must be not less than six (6) inches in dia at the point or ten (10) inches at the butt. It must have a uniform from butt to tip, have the bark removed, be free from short bends, straight line from the center of the butt to the center of the tip sh wholly within the body of the pile. All knots or blemishes must be med off close and even with the body of the pile. The lower ends sh cut square or tapered as may be directed by the engineer.

Timber or lumber to be creosoted, unless otherwise specified, shall ply with the requirements given above and shall be long-leaf yellow It must be treated with the creosote oil described in paragraph 102 the treatment so performed that the wood will absorb not less than t (12) pounds of oil per cubic foot for lumber having a minimum cross-se not over four (4) inches, or eight (8) pounds per cubic foot for lumber h a minimum cross-section of not less than six (6) inches.

Log Cribbing (U. S. Forest Road Specifications)

Log cribbing shall be built to the lines and grades given by the eng and constructed in conformity with the plans or as directed by the eng

Materials.—The contractor shall secure and prepare or shall furni his own expense all necessary logs, timber, hardware, etc., under the c tions and as called for under the heading "Material" for "Log Bridges

Construction.—The cribbing shall be supported on mudsills with flat lower surfaces placed as shown on the plans.

All logs, including face logs, tie logs, mudsills and anchor logs, sha properly notched together and drift bolted as shown on the plans.

The minimum lengths and sizes of logs shall be as shown on the Each course of logs shall break joint with the adjacent courses. The le of tie logs required for the proper support and anchorage of the cri shall be as determined by the engineer.

The face and tie logs are to be so notched together, and hewn if neces that the face logs will be in contact with each other throughout their

ı, except that in case a satisfactory rock backfill is placed against the ogs the engineer may permit open spaces not exceeding 4 inches in between the face logs. When permission to use such spaces is given, ɔck backfill shall be carefully placed, using the larger rocks adjacent logs and backing up with the smaller rocks in such manner that earth ner material will not escape or be washed out.

/ment.—Payment will be made by the linear foot of face logs in place lete at the unit bid price, which price shall include the furnishing and ıg of transverse mudsills, tie logs, anchor logs and drift bolts. Such ɔid price shall be payment in full for all materials, labor, excavation, illing and incidental work required for the construction of the cribbing lete. The measurement of log cribbing shall include only the linear f face logs, or longitudinal mudsills when such are used, and will not le transverse mudsills, tie logs or anchor logs.

120. Paints

A. General.—All paints shall be shipped in strong, substantial con-s, plainly marked with the name and weigh tof paint content, and and address of the manufacturer. When so requested, samples and sis of all pigments, oils, thinners, or driers used, or paints furnished be supplied by the manufacturer within ten (10) days after request is therefor.

nts shall consist of pigments of the required fineness and composition, d to the desired consistency in raw or boiled linseed oil, to which shall ded additional oil, and a thinner, or a drier, or both. All pigments, hinners, and driers used shall be of the best quality, free from adulter-of any kind, and shall comply with the requirements given below for materials.

B. Paint Paste.—All paint paste shall consist of the specified pig-or pigments ground in linseed oil to the required consistency. The must be so prepared that it is uniform in composition and consistency, ot cake or segregate in the retainers, and will easily break up in oil m a smooth, uniform paint of brushing consistency which will not run ıg. The color, hiding power, and weight per gallon when specified be the same or equal to the approved sample.

C. Ready Mixed Paints.—To prepare a paint so that it will have the ed consistency and curing properties for the use intended, the paste be mixed with sufficient linseed oil, turpentine, and drier to produce a having these properties. Unless otherwise specified, the exact quan-f linseed oil, turpentine, and drier required for this purpose shall be nined by the engineer.

D. Raw and Boiled Linseed Oil.—Raw linseed oil must be strictly well-settled linseed oil, perfectly clear and not show any sediment or more than two-tenths (0.2) per cent when heated for one-half (½) t temperature between 105 and 130°C.

ed linseed oil shall be made by heating the raw linseed oil to at least ., with oxides of lead and manganese for a sufficient length of time to the proper combination of the constituents. After this it shall be ly clarified by settling or other suitable treatment.

oil shall be rejected if it shows the presence of any foreign matter, than lead or manganese or compounds of these metals.

/ and boiled linseed oil shall conform to the following requirements:

Material	Raw linseed oil		Boiled linseed oil	
Tests	Minimum	Maximum	Minimum	Maximum
Specific gravity at 15.5°C./15.5°C.	0.932	0.936	0.937	0.945
Acid number	.....	6.00	.....	8.00
Saponification number	189	195	189	195
Unsaponificable matter, per cent	.....	1.50	.....	1.50
Refractive index at 25°C	1.479	1.4805	1.479	1.484
Iodine number (Hanus)	180	......	178	
Ash, per cent	.....	......	0.2	0.7
Manganese, per cent	.....	......	0.03	
Calcium, per cent	.....	......	.....	0.3
Lead, per cent	.....	......	0.1	

120E. Turpentine or Thinner.—Turpentine shall be the distillate monly known as Gum Turpentine or Spirits of Turpentine which is dis from pine oleoresins or the product secured from resinous wood by extra with volatile solvents, by steam or by destructive distillation. Eith both of these two products; gum spirits or wood turpentine, shall b nished for use when so specified.

The turpentine shall be clear and free from suspended matter and
The color shall be Standard or better.

The specific gravity shall not be less than 0.862 nor more than 0.8 15.5°C.

The refractive index at 15.5°C. shall not be less than 1.468 nor more 1.478.

The initial boiling point shall not be less than 150 nor more than 1
Ninety (90) per cent of the turpentine shall distil below 170°C.

The polymerization residue shall not exceed two (2) per cent, a refractive index at 15.5°C. shall not be less than 1.500.

120F. Drier.—The drier shall be composed of lead and manganese in combination with pure linseed oil and solvent. It must be free adulterants, sediment and suspended matter. It shall not flash below in an open tester or 72°F. in a closed Abel tester.

120G. Pure White Lead. *Dry Pigments.*—The pigment shall be a basic carbonate of lead of the formula $2PbCO_3PbOH_2$, containing sixt (65) to seventy-five (75) per cent of lead carbonate, and not more tha (2) per cent of total impurities, including moisture. It shall be grou such fineness that it will all pass a 200-mesh sieve and contain no than two (2) per cent material retained on a 325-mesh sieve.

Paste.—The paste shall be the dry pigment ground in oil in the m specified above. It shall consist of:

	Percentages	
	Minimum	Maxin
Pigment	90	92.
Linseed oil	8	10.
Moisture and other volatile matter	..	0.
Coarse particles and "skins" (total residue retained on a 325-mesh sieve based on pigment)	..	2.

Ready-mixed Paint.—The ready-mixed paint shall be prepared fro paste in the manner specified above.

120H. Pure Zinc-oxide Paint. *Dry Pigment.*—The dry pigmen consist of pure oxide of zinc which shall contain not less than ninet (98) per cent of zinc oxide nor more than two-tenths (0.2) per c sulphur or two (2) per cent of total impurities including moisture pigment shall be so ground that it will all pass a 200-mesh sieve.

Paste.—The paste shall be the dry pigment ground in oil as above sp It shall consist of:

	Percentages	
	Minimum	Maxir
Pigment	82	86.
Linseed oil	14	18.
Coarse particles and "skins" (total residue left on a 200-mesh sieve, based on pigment)	..	0.
Moisture and other volatile matter	..	0.

ıdy-mixed Paint.—The ready-mixed paint shall be prepared from the
in the manner specified above.

›I. **Red Lead.** *Dry Pigment.*—The dry pigment shall consist entirely
: oxides of lead which shall contain from eighty-five (85) to ninety-five
per cent of PB_3O_4, not more than one (1) per cent of total impurities
hall be so ground that not more than three-tenths (0.3) per cent is
ied on a 200-mesh sieve.

ste.—The paste shall be the pigment ground in oil as above specified.
ıll consist of:

	Percentages	
	Minimum	Maximum
nent	92	94.0
eed oil	6	8.0
sture and other volatile matter	..	0.5
rse particles and "skins" (total residue ft on a 200-mesh sieve)	..	0.5

dy-mixed Paint.—The ready-mixed paint shall be prepared from the
in the manner specified above.

resulting paint, when mixed in the proportions given below and
ed on a smooth, vertical, iron surface, shall dry hard and elastic without
ıg, streaking, or sagging.

Red-lead paste	20 lb.
Raw linseed oil	4½ pt.
Turpentine	2 gills
Liquid drier	2 gills

J. **Leaded Zinc Oxide.** *Dry Pigment.*—The dry pigment shall be a
inc oxide and a normal or basic lead sulphate. The pigment shall be
und that it will all pass a 200-mesh sieve and the zinc oxide shall not
n more than one (1) per cent of soluble salts nor more than one and
nths (1.5) per cent of total impurities including moisture.

s type of paint shall be divided into two brands, High Leaded and Low
d. The high-leaded paint shall contain not less than sixty (60) per
f zinc oxide and the low-leaded paint not less than ninety-three (93)
of zinc oxide, the remaining pigment in each case to be a normal or
ead sulphate.

e.—The paste shall be the dry pigment ground in oil as above specified.
l consist of:

	Percentages	
	Minimum	Maximum
ent	....	88.0
ed oil	12.0	
ture and other volatile matter	....	0.5
se particles and "skins" (total residue t on a 200-mesh sieve based on pigment)	....	0.5

ly-mixed Paint.—The ready-mixed paint shall be prepared from the
n the manner specified above.

120K. White Basic Sulphide. *Dry Pigment.*—The pigment sha the sublimated product prepared from lead sulphide ores. The pigment be so ground that it will all pass a 200-mesh sieve, contain not more five-tenths (0.5) per cent of material retained on a 325-mesh sieve and the following composition:

Lead oxide........................ eleven (11) to eighteen (18) pe
Zinc oxide........................... not more than nine (9) pe
Total impurities, including moisture....... not more than one (1) pe

The remainder shall be lead sulphide.

Paste.—The paste shall be the pigment ground in oil as above spe It shall consist of:

	Percentages	
	Minimum	Maxim
Pigment................................	89	91.(
Linseed oil................................	9	11.(
Moisture and other volatile matter..........	..	0.'
Coarse particles and "skins" (total residue retained on a 325-mesh sieve, based on pigment)................................	..	0..

Ready-mixed Paint—The ready-mixed paint shall be prepared fro paste in the manner specified above.

120L. Tinted Paint with White Base. *Dry Pigment.*—The ingre used in preparing this pigment shall comply with the requirements above for said ingredients. The pigments shall be composed of:

	Percentages	
	Minimum	Maxin
White lead (basic carbonate, basic sulphate, or a mixture thereof)..................	45	70
Zinc oxide (ZnO).........................	30	55
Silica, magnesium silicate, aluminum silicate, barium sulphate, pure tinting colors, or any mixture thereof.....................	0	15

In no case shall the sum of the basic lead carbonate, basic lead sul and zinc oxide be less than eighty-five (85) per cent of the mixture. lead and zinc pigments may be introduced in the form of any mixtu pared from basic carbonate white lead, basic sulphate white lead, zinc or leaded zinc, provided the above requirements as to composition ar

Liquid.—The liquid in semipaste paint shall be entirely pure, raw or r linseed oil; in ready-mixed paint it shall contain not less than ninet per cent pure raw linseed oil, the balance to be combined drier and th The thinner shall be turpentine, volatile mineral spirits, or a mixture tl

Semipaste.—The paste shall be the pigment ground in oil as above fied. It shall mix readily in all proportions without curdling with linse turpentine, or volatile mineral spirits, or any combination of thes stances The color, hiding power, and weight per gallon when spe shall be not less than that of the approved sample. The paste shall c of:

	Percentages	
	Minimum	Maximum
ment	73	77.0
seed oil	23	27.0
isture and other volatile matter	..	0.7
ırse particles and "skins" (total residue n a 200-mesh sieve based on pigment)	..	0.5

ıdy-mixed Paint.—The ready-mixed paint shall be prepared from the in the manner specified above. The weight per gallon shall be not less fifteen and three-quarter (15¾) pounds. The paint shall consist of:

	Percentages	
	Minimum	Maximum
nent	62	66.0
ıid (containing at least 90 per cent nseed oil)	34	38.0
ter	..	0.5
rse particles and "skins" (total residue ɛtained on a 200-mesh sieve, based on igment)	..	0.5

M. Graphite. *Dry Pigment.*—The dry pigment shall be a pure, al flake graphite and silicate rock to which may be added a small ntage of carbon black, iron oxide, or other oxides needed to secure a d tint or color. The pigment shall be so ground that it will all pass a ıesh sieve and contain not more than ten (10) per cent of material retained 325-mesh sieve. The prepared pigment must contain not less than forty-45) per cent of natural graphite.

te.—The paste shall be the pigment ground in oil as above specified. ıll consist of:

	Percentages	
	Minimum	Maximum
nent	62	66.0
eed oil	34	38.0
sture and other volatile matter	..	0.80
rse particles and "skins" (total per cent ı a 325-mesh sieve, based on the pigment)	3	6.0

dy-mixed Paint.—The ready-mixed paint shall be prepared from the in the manner specified above.

resulting paint when mixed in the proportions given below, and ed on a smooth, vertical, iron surface shall dry hard and elastic without ıg, streaking, or sagging. It shall consist of:

	Percentages	
	Minimum	Maximu
Pigment	30	35
Boiled linseed oil	65	70
Japan drier	5	6
Turpentine and volatile matter	3	6

CLEARING AND GRUBBING (WASHINGTON STATE SPECIFICATIONS)

Clearing.—The right-of-way must be cleared to the width of —— on each side of the center line, or as shall be designated by the engi all trees, brush, and other vegetable matter within the space desig to be cut down, and the same, together with all other logs, brushwood fences already down, shall be burned or removed from the grounc the engineer may direct, so as not to injure the adjoining lands or to obs the line of the fences along the boundaries of the said right-of When the embankments exceed two feet in height it will be required to cu trees, brush, and stumps close to the ground.

Light clearing shall include the removal of all standing trees of a up to one foot in diameter, together with all other logs, brush, and vegetable matter already down or lying loose on the ground.

Heavy clearing shall include the removal of all standing trees ove foot in diameter, together with all other logs, brush, and other vege matter already down or lying loose on the ground.

Grubbing.—From the space required for the roadbed and nece slopes and side drains, and whatever additional space may be requir the engineer, except where the excavations are three feet or more in c vegetable matter embedded in the ground shall be grubbed up, and rer or disposed of as the engineer may direct, and only the area so gr shall be estimated.

Clearing and Grubbing (U. S. Forest and Road Specifications).—Thi shall include all clearing, grubbing, and disposal of timber.

The right-of-way must be cleared on each side of the center line road to the full width indicated by the plans, or as the engineer may re All trees, brush and other vegetable matter within the space designatec be cut down and all tree branches extending into the right-of-way hang within 20 feet of the ground shall be cut off. The edge of the cl shall present a fairly regular and uniform alignment, except that fine mens of trees shall be left standing when in the judgment of the en they will not be injurious to the road. All stumps and all trees, the st of which are not to be grubbed, shall be cut not more than two feet abo ground.

From the space required for the roadbed and necessary slopes an drains except where the embankments at the point in question are thre or more in height, all stumps, large roots, and other imbedded wo vegetable matter shall be grubbed or blasted from the ground.

The contractor will be required to use merchantable timber cut fro right-of-way for the drainage or other structures for which it may be su and for which he would otherwise be compelled to cut merchantable t from adjacent government land. All clear and sound logs or poles h a top diameter of four inches or more and a length of four feet or mor be considered as merchantable timber in the operations under these s cations. The merchantable timber in excess of that needed in the con tion of the road which must be cut in the clearing of the right-of-way be felled in the right-of-way, cleared of limbs and brush, sawed intc standard lengths as may be designated by the engineer and skidde workmanlike piles at the edge of the right-of-way, before grading is u taken. The title to all such timber cut from National Forest lands remain with the United States subject to disposal by the Forest Se U. S. Department of Agriculture, under its regular procedure.

ll other than merchantable trees, together with all brush, stumps, roots, other débris, must be placed in neat conical piles with the small material ie bottom and the large limbs and other materials stacked on the outside ie pile in such a manner as to be completely consumed when the pile is ied. In case the burning is to precede the construction operations, the ; may be placed in the center of the right-of-way, otherwise, the piles ild be placed in the most convenient place to the side of the right-of-way re they may be burned without damage to the surrounding forest cover. o case will it be permissible to merely throw the refuse outside of the t-of-way or to place it in windrows at the side of the right-of-way.

ie material placed in piles shall be burned by the contractor at such time in such manner as absolutely to prevent the fire from spreading to areas ining the right-of-way.

irticular care must be exercised to avoid producing an unsightly appear- by burning or scorching green trees standing along the edge of the right-ay. Any trees permanently defaced in this manner shall be cut down disposed of as the engineer may direct.

hen upon the advice of the Forest Supervisor of the Natural Forest con-ed the engineer determines that the proper protection of the National st from fire demands that burning operation shall be discontinued, the ractor shall make such disposal on the ground of the material as the ieer may indicate.

EXCAVATION (WASHINGTON STATE SPECIFICATIONS)

ider the head of excavation shall be included all excavations required he formation of the roadbed, the digging of all ditches, cutting new nels for streams, preparing foundations, the altering of all highway or ite roads and all excavations in any way connected with or incidental ie construction of the road, and the expense of hauling and depositing : in embankments wherever required.

ıbankments.—Under the head of embankments shall be included nbankments for any of the purposes mentioned not formed from excava- taken from the prism of the road or other necessary excavations.

l grading shall be done and estimated by the cubic yard, measured e excavation, except material borrowed for embankment, which shall be ured in embankment, and shall be comprised under heads, viz.:

irth, Hard-pan, Loose Rock, Solid Rock, Shell Rock, and Solid Rock. ow.

irth.—Earth will include clay, sand, loam, gravel, and all hard material can, in the opinion of the chief engineer, be reasonably plowed, and arthy matter or earth containing loose stones or boulders intermixed, all other material that does not come under the classification of hard- loose rock, solid rock, shell rock, and solid rock borrow.

ırd-pan.—Hard-pan will include material, not loose or solid rock, cannot, in the opinion of the chief engineer, be reasonably plowed on ınt of its own inherent hardness.

ose Rock.—Loose rock will include all stone and detached rock, found parate masses, containing not less than one cubic foot, nor more than ialf cubic yard, and all slate or other rock, soft or loose enough to be ved without blasting, although blasting may occasionally be resorted to.

lid Rock.—Solid rock will include all rock in place, and boulders meas- : one-half cubic yard and upwards, in removing which it is necessary sort to drilling and blasting.

ell-rock Excavation.—Shell-rock excavation will include all deposits osed entirely of rock in masses of less than one cubic foot which have en off from the cliffs above the roadbed, but will only be estimated in large deposits.

lid Rock Borrow.—Solid rock borrow shall consist of solid rock, accord-o above classification, excavated outside of the regular cross-sections e cuts for the roadbed, and placed and measured in embankment.

AVATION (NEW YORK STATE SPECIFICATIONS, ITEMS NO. 2 TO 46)

Item 2—Earth Excavation
Item 3—Rock Excavation

. Under these items the Contractor shall grade the entire length of vay, ditches and side slopes to the required lines and grades; shall make :cavations for culverts, underdrains, catch basins, leaching basins, and

other structures except posts; shall grade connecting public highway directed and remove spongy material from the subgrade to the de required—all as shown on the plans or as directed by the engineer.

This item includes the excavation, filling, and rolling necessary to plete the road and all structures connected therewith except as noted ab and includes the removal of all objectionable material for the full widt the improvement except as noted under section 1.1, and the filling to required grade with acceptable material of all areas originally below required grade, or excavated below grade under orders of the engineer.

Backfill for structures, old macadam excavated, and sod ordered rem from the site of a new embankment, shall be paid for as Earth Excava

2.2. All suitable materials from the excavation shall be used so fa practicable in making embankments, building up low places on the grade or shoulders, and such other places as directed.

2.3. Surplus material shall be placed in embankments, shall be used extending the shoulders or shall be deposited in spoil banks, as dire by the engineer. All surplus materials shall be removed and disposed directed by the engineer before the subgrade or shoulder rolling is comp and before any stone is placed on the roadway.

2.4. If there is not sufficient suitable material to complete the gra and to bring the subgrade to the required height, the contractor shall bo additional material from the sides of the roadway or from other borrow as directed by the engineer so that the established grade for the road, emb ments, etc., will be secured. All borrow pits outside the highway sha acquired by the contractor at his own expense, and any borrow pits adjacent to the highway shall be left in a neat and satisfactory cond and shall be thoroughly drained.

2.5. The contractor shall remove boulders and all muck, quicks soft clay, and spongy material which will not consolidate under the r from the subgrade to a depth to be determined by the engineer, and the space with acceptable materials from the excavations, or with sto gravel, as directed. If stone or gravel is used, the same will be pai at the contract price bid for item Foundation Course. After all d have been laid and the surface of the subgrade has been properly sha it shall be thoroughly rolled and compacted with an approved self-prop roller weighing not less than 10 tons. Water puddling shall be res to in case the soil requires it. Care shall be taken not to roll clay fou tions too much, thus developing a plastic condition. All hollows depressions which develop shall be filled with acceptable material, and subgrade shall again be rolled. This process of filling and rolling sh repeated until no depressions develop. In places where the charact the material makes the use of such a roller impracticable, a ligher one be permitted. The subgrade shall not be muddy, or otherwise uns factory when the foundation course is placed upon it. All culverts, dit and drains shall be satisfactorily completed to drain effectively the higl before the placing of any pavement will be permitted. The shoulders sha rolled and left in a compact and satisfactory condition at the compl of the pavement.

2.6. Embankment shall be formed of suitable materials. If forme stone, all reasonable precautions must be taken to insure a solid emb ment. The upper surface of the embankment shall be rolled and left satisfactory condition and approximately true to line and grades. I stone shall not project within 6 inches of the finished subgrade, an hollows, and depressions shall be filled with the smaller stone from excavation, with gravel or with other acceptable material. Ston embankments shall not be used nearer than 6 inches to the surface of shou

Where the filling is less than 2 feet in depth all vegetable matter sha removed from the original surface. Where necessitated by the exi slope, the original surface shall be trenched or otherwise broken up b placing new embankment thereon.

Where the depth of fill is less than 6″ the underlying surface mu plowed or scarified to get a good bond. The price for such work is incl in the price bid for excavation.

Embankment shall be constructed in successive horizontal layers exceeding 12 inches in thickness; when concrete is to be placed the these layers shall not exceed 6 inches in thickness. Each layer shall ex across the entire fill and shall be thoroughly rolled and compacted approved methods. If impacticable to use a heavy roller for this w grooved roller shall be used.

7. At all intersecting public highways the contractor shall grade back sufficient distance with acceptable materials, as directed by the engineer iat a smooth riding and satisfactory junction will be produced.

3. The quantity of excavation to be paid for under Items 2 and 3 shall ie number of cubic yards of material, measured in its original position, vated and disposed of as directed by the engineer, and the limits shall exceed those shown upon the plans or fixed by the engineer.

ie price bid for Earth Excavation shall include the removal of all mate-, as specified under section 2.1—except as provided below for Rock ivation,—the placing of same in embankment or spoil, the rolling, pacting, grading, and all other work incidental thereto.

o direct payment shall be made under Items 2 or 3 for work in connection contractor's plant, nor for his other requirements in carrying out the isions of this contract, but compensation therefor shall be considered iving been included in the prices stipulated for the various items of the ract.

ie price bid for Item 3 shall include the removal of all boulders of more 13 cubic feet and all hard ledge rock and the placing of same in inkment or spoil if not used under other items of the contract, and rolling, icting, grading, and all other work incidental thereto. Boulders of than 13 cubic feet, and all soft or disintegrated rock which can be ›ved with pick and shovel, shall not be paid for under Rock Excavation, under Earth Excavation. The price bid for the items shall include ibor, materials, supplies, and plant and incidentals necessary to com- the work.

Item 4—Overhaul

.. If the haul on any material either from cuts or borrow pits made :cordance with directions from the engineer exceeds 2000 feet it shall assified as overhaul.

r each 100 feet of haul greater than 2000 feet the contractor shall ve the price bid for Overhaul per cubic yard of all material so moved, ured in its original position.[1]

ie price bid shall include all labor, appliances, and incidentals necessary mplete the work.

CONSTRUCTION METHODS

Preparing Fine Grade[2]

ider this item the contractor shall prepare the fine grade to receive ient in conformity with the lines and grades as shown on the plans or as red by the engineer.

fore any paving material is placed upon the fine grade it shall be shaped ne and grade and compacted with an approved self-propelling roller hing not less than 5 tons. All hollows and depressions which develop r rolling shall be filled with acceptable material and shall again be rolled. process of shaping, rolling, and filling shall be repeated until no depres- develop. The subgrade shall not be muddy or otherwise unsatisfactory i the pavement is placed upon it. If the fine grade becomes rutted or aced due to any cause whatsoever, the contractor shall regrade same out additional payment.

ie quantity to be paid for under this item shall be the number of square s of the fine grade prepared in accordance with the plans or the orders e engineer, on which pavement is placed.

ie price bid per square yard shall cover all labor and incidental work ifying if necessary), to form, trim, and compact the fine grade under- i the pavement to the lines and grades as shown on the plans or as ·ed by the engineer, and the furnishing and placing of the necessary on any scarified area.

STATE HIGHWAY DEPARTMENT OF TEXAS

Item 32. Subgrade Treatment

.1. **Description.**—This item shall consist of treating a gumbo, adobe, or faulty subgrade with a stabilizing course of granular material to perfect indation for base courses, surface courses, or pavements. It shall be

[1] pecifications should stipulate that the amount of overhaul will be com- l by the Mass Diagram Method.

[2] lew York.

constructed in accordance with the specifications and in conformity with line, grade, and typical cross-section shown on plans.

32.2. Materials.—The materials for this course will be noted on the pl In general, they will be coarse sand, fine gravel, cinders, or other l material of a granular nature, of such quality and properties as the engi may approve in writing. Unless otherwise prescribed, the material shal such that all will pass the ½″ screen, and 40 % will be retained on the 10-n screen.

32.3. Construction Methods.—The subgrade to be treated shall have l completed to line, grade, and typical cross-section. The granular mat shall then be delivered and evenly spread on the subgrade in such quan that when the work is completed the requirements of the typical cr section will have been fulfilled. It shall be the charge of the contractor the required amount of material shall be delivered in each 100′ station uniformly distributed throughout each station.

32.4. The material shall then be incorporated with the material of subgrade as required on the plans and rolled and sprinkled as directed. contractor shall work and dress the surface as directed until the tre subgrade is set up hard and smooth in accordance with the grade and ty cross-section required, and so maintained until the proposed base cours surface course or pavement is in place.

32.5. Method of Measurement.—Work and acceptable material furni shall be measured by the cubic yard of material, loose measurement.

32.6. Basis of Payment.—The material furnished as prescribed by item shall be paid for at the contract unit price per cubic yard for Subg Treatment Material. The work performed as prescribed for this i measured as provided above, shall be paid for at the contract unit price per cubic yard for Subgrade Treatment, which price shall be full com sation for loading all material, hauling not over ¼ mile, delivered on the r spreading and finishing, all labor, equipment, tools, and incidentals neces to complete the work except screening material, rolling, and sprink Hauling material into each quarter mile beyond the first quarter mile be paid for at the contract unit price per cubic yard bid for Material Ha Additional Quarter Mile. Screening will be paid for at the contract price bid per cubic yard for Screening.

Item 39. Foundation Course, Run-of-bank Gravel[1]

a. **Work.**—Under this item the contractor shall furnish and pla foundation course of run-of-bank gravel of the depth and in the p called for on the plans and ordered by the engineer.

b. **Material and Placing.**—All gravel shall be of hard, durable stone well graded. The proportions of coarse and fine particles shall be s factory to the engineer. Before using run-of-bank gravel in the work same shall be tested to determine its suitability. Should at any time du the work and for any reason the gravel fail to maintain suitable propor of the coarse and fine particles, the contractor shall, by the additio selected material and satisfactory manipulation, produce a material me the above requirements.

No segregation of large or fine particles will be allowed, but the grav spread shall be well graded with no pockets of fine material.

In cases where the finished thickness of the course is to be more thaı the gravel shall be spread, rolled, and filled in separate layers as directe the engineer.

After laying, this course shall be thoroughly rolled with an approved r weighing not less than 10 tons, and shall then be filled as directed and a rolled and the filler broomed until the stones are bound together and t oughly compacted. All holes or depressions found in rolling shall be f with gravel and the surface shall be rerolled until it conforms to the lines grades as shown on the plans. In all cases a sufficient but not exce amount of fine material (coarse sand or screenings) shall be used to fi voids. In limited areas where the use of a roller is impracticable h tampers may be used to consolidate the material. In all cases the f dation course must be so thoroughly compacted that it will not wave u the roller. This course shall not be laid in excess of 500 lin. ft. without t rolled and thoroughly filled so as to render it waterproof, and thereby vent the softening of the subgrade.

[1] New York.

Measurement and Payment.—The quantity of foundation course to be for under this item shall be the number of cubic yards of compacted :rial in place as shown on the plans or ordered by the engineer.

ıe price bid shall cover the furnishing, placing, filling, and rolling of the :rial and all labor and incidental expenses necessary to complete the :.

:m 39A. Foundation Course, Run-of-bank Gravel, Loose Measure

ıe general specifications for Item 39 shall apply, except that the quantity : paid for will be the number of cubic yards, loose measure, incorporated e work, as directed by the engineer.

Item 40. Foundation Course, Screened Gravel[1]

Work.—Under this item the contractor shall furnish and place a founda- course of screened gravel of the depth and in the places called for by the s or as ordered by the engineer in accordance with Sec. *f* of item .vation.

Drainage.—No gravel shall be placed on the road until the culverts ompleted and proper drainage provided and subgrade shaped and rolled ıe satisfaction of the enginner.

Material and Placing.—All gravel shall be hard, durable stone satis- ›ry to the engineer. The particles shall be of such size as will pass ıgh a 3¾″ circular hole and will be retained on a 1½″ circular hole and be well graded. In cases where the finished thickness of the course be more than 6″ the gravel for it shall be spread, rolled, and filled in two rate courses.

ter the subgrade has been properly prepared a course of 1″ of approved or cinders shall be evenly spread upon the grade, after which the ned gravel shall be spread evenly, so that it will have after rolling the er thickness. No segregation of large or fine particles will be permitted, :he gravel shall be well graded with no pockets of fine material.

Rolling and Filling.—After the gravel has been spread loose it shall be ɔughly rolled with an approved self-propelling roller weighing not less 10 tons.

ıe rolling must begin at the sides and continue toward the center until ɔ is no movement of the stone ahead of the roller. After the gravel is ɔughly compacted No. 1 size gravel and sand shall be thoroughly spread ı the surface and kept in with rattan or steel brooms and rolled.

ıis course shall not be laid in excess of 500 lin. ft. without being rolled thoroughly filled so as to render it waterproof and thereby prevent the :ning up of the subgrade. Should the subgrade material become churned ıto or mixed with the foundation course through the contractor's hauling it or working on it when the subgrade is in a wet condition, the contractor , at his own expense, remove such mixture of subgrade material and el and replace the foundation course.

In Case of Two Courses.—When two courses of screened gravel are each course shall be treated separately by rolling and filling as described 're.

Measurement and Payment.—The quantity to be paid for under this shall be the number of cubic yards of compacted material in place and be computed by multiplying the finished cross-section of the foundation se as shown upon the plans or ordered by the engineer, by the length ;ured along the axis of the pavement.

ıe price bid shall cover the furnishing, placing, filling, rolling of the :rial, and all labor and incidental expenses necessary to complete the : satisfactorily.

Item 41. Foundation Course, Field or Quarry Stone[1]

Work.—Under this item the contractor shall furnish and place a founda- course of stone of the depth and in the places called for by the plans, or 'dered by the engineer in accordance with Sec. *f* of item Excavation.

Drainage.—No stone shall be placed on the road until the culverts :omplete and proper drainage provided and subgrade shaped and rolled ıe satisfaction of the engineer.

Material and Placing.—After the subgrade has been properly prepared urse of 1″ of approved sand, gravel, or cinders shall be evenly spread ı the grade. This 1″ course of sand, gravel, or cinders shall not be

'New York.

estimated as a part of the depth of the foundation course, but payment same shall be included in the price bid for this item.

Stone used in the foundation course shall be of hard, sound, and dur quality, acceptable to the engineer.

The depth of the stone shall in no case be greater than the depth speci for the course, the width shall not be greater than the depth, or more than and the length shall not be greater than one and one-third times the de or more than 12″. The distribution of the stone shall be of a uniforr satisfactory to the engineer. In cases where the finished thickness of course is more than 9″ the foundation course shall be laid in two courses the first course completely filled and rolled before constructing the sec Stone of greater than permissible dimension shall be broken to proper before placing. All flat stone and fragments having an average dimen over 6″ shall be roughly placed by hand on their broadest edge with t longest dimension crosswise of the road and in as close contact as poss The smaller stone shall then be shoveled or forked upon the surface of course.

After laying, this course shall be thoroughly rolled with an appro self-propelling roller weighing not less than 10 tons. After rolling, course shall be tested with a line 25′ in length and any depressions ove in depth shall be eliminated by the use of broken stone. The course s then be rerolled and filled with broken stone uniformly distributed thoroughly rolled, after which coarse sand or screenings shall be used t the voids and rolled. In all cases the foundation course shall be so thorou compacted that it will not weave under the roller. Gravel or selected s may be substituted for the broken-stone filler if so designated on the p or in the itemized proposal. This course shall not be laid in excess of lin. ft. without being rolled and thoroughly filled so as to render it wa proof and thereby preventing the softening of the subgrade. Should subgrade material become churned up into or mixed with the founda course through any reason whatsoever, the contractor shall, at his expense, remove such mixture of subgrade material and stone and rep the foundation course.

d. **Measurement and Payment.**—The quantity to be paid for under item shall be the number of cubic yards of compacted material in place shall be computed by multiplying the finished cross-section of the founda course as shown upon the plans or ordered by the engineer by the le measured along the axis of the pavement.

The price bid shall cover the furnishing, placing, filling, and rollin all materials, and all labor and incidental expense necessary to com the work.

Item 33. Reconstructed Base Course[1]

33.1. Description.—This item shall consist of the reshaping of the exis surface and the addition of the required amount of new material, all of w shall be compacted to form a foundation course for other base courses o surface courses or pavements. The additional material shall conform to requirements for material of the type of the original course as prescribe these specifications, and the item shall be constructed in accordance these specifications and in conformity with the lines, grades, and ty cross-section shown on the plans. The item name corresponding to original course shall be given on the plans.

33.2. Construction Methods.—The existing surface shall be scarifiec the full width of the proposed base course and to such uniform depth b the proposed finished surface as will eliminate all existing depressions irregularities and permit of uniform reshaping. Any existing bitumi mat of more than ½″ thickness shall be removed from the work.

33.3. After scarifying, the material shall be shaped to conform to required section, the required material added in a uniform course of depth that when compacted the finished surface will conform to the grade, and typical cross-section. The course shall then be rolled sprinkled if directed, and finished and maintained as required in the spe cations for the base course corresponding to the original constructio noted on the plans.

33.4. Methods of Measurement and Basis of Payment.—The worl scarifying, loosening, and shaping the original construction shall be meas by the square yard and paid for at the contract unit price per square yarc for Reconstructed Base Course.

[1] Texas.

;. All other work performed as prescribed, and all accepted material be measured by the cubic yard, loose measurement. The material hed as prescribed shall be paid for at the contract unit price per cubic or the base-course material corresponding to the original constructed ed on the plans when such price is requested and tendered in the pro- When such price is not so requested, right-of-way and royalty charges material in the pit will not be a charge to the contractor.

. The work performed as prescribed shall be paid for at the contract per cubic yard bid for the item named on the plans as the type of al construction, which price shall be full compensation for loading all al, hauling not over ¼ mile, delivering on the road, spreading and ng, all labor, equipment, tools, and incidentals necessary to complete ork except rolling, and sprinkling. Hauling material into each quarter eyond the first quarter mile shall be paid for at the contract unit price bic yard bid for Material Hauled Additional Quarter Mile.

Item 34. Shell Base Course[1]

. **Description.**—This item shall consist of a foundation course for e courses, or other base courses, shall be composed of shell, and shall be ucted on the prepared subgrade in accordance with these specifications conformity with the lines, grades, compacted thickness, number of nent courses, and typical cross-section shown on the plans.

. **Material.**—The shell shall consist of sound particles of oyster, clay, er shells equally acceptable to the engineer, and shall not contain more 5% of mud, clay marl, or loam.

. **Construction Methods.**—The material shall be delivered and spread nd on the prepared subgrade or completed base course to such depth when compacted, the thickness shown on the plans will be secured and to conform to the typical cross-section. Side forms and either cubi- cks or center guide forms of proper size shall be used to fix the depth loose material. It shall be the charge of the contractor that the ed amount of material shall be delivered in each 100′ station and mly distributed throughout each station.

. The work shall be rolled and sprinkled or opened to traffic as directed. ntractor, as often as directed, shall work and dress the surface so that oss-section shall continue uniform and true to line and grade until ed. When the typical cross-section requires that this item be con- ed in more than one course, each additional course shall be constructed ndently after the previous one has been completed and accepted, all scribed above.

. **Method of Measurement.**—Work and accepted material hauled to d shall be measured by the cubic yard of material, loose measurement, vered on the road.

. **Basis of Payment.**—The material furnished as prescribed by this hall be paid for at the contract unit price per cubic yard bid for Shell. ork performed as prescribed by this item and measured as provided shall be paid for at the contract unit price per cubic yard bid for Shell Course, which price shall be full compensation for loading all material, g not over ¼ mile, delivering on the road, and finishing, all labor, nent, tools, and incidentals necessary to complete the work except and sprinkling. Hauling material into each quarter mile beyond the uarter mile shall be paid for at the contract unit price bid per cubic r Material Hauled Additional Quarter Mile.

Item 35. Caliche Base Course[1]

Description.—This item shall consist of a foundation course for courses, or other base courses, shall be composed of caliche, and shall structed on the prepared subgrade in accordance with these specifica- nd in conformity with the lines, grades, compacted thickness, number ponent courses, and typical cross-section shown on the plans.

Material.—Caliche shall consist of a natural mixture of approxi- equal proportions of calcareous dust and quartz sand with or without sence of gravel or small stones, all of which, when tested, shall pass screen, and shall not contain more than 10% clay.

Construction Methods.—The material shall be delivered and spread d on the prepared subgrade to such depth that when compacted the

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thickness shown on the plans will be secured and shaped to conform · typical cross-section. Side forms and either cubical blocks or center forms of proper size shall be used. It shall be the charge of the cont that the required amount of material shall be delivered in each 100′ s and uniformly distributed throughout each station.

35.4. If, in the opinion of the engineer, it be practicable to do so, the c shall be puddled with water before being finally shaped and comp This puddling may be done either in the pit before the material is haule the road or it may be done by sprinkling with water after the materi been spread upon the subgrade. In case puddling is done in the materi the caliche shall at once be hauled onto the road, spread by means of rakes, or shovels, shaped, and rolled before it has dried out. In case pu is to be done after it has been spread upon the subgrade, the surface be thoroughly harrowed, plowed, or otherwise opened up, during the p of sprinkling, in order to insure the proper puddling of the caliche. being thoroughly puddled, to the satisfaction of the engineer, the s shall be shaped to a uniform thickness and cross-section and the succ course of material shall be added and puddled in the same manner. succeeding course shall be placed and puddled as soon after the pre one as practicable.

35.5. The work shall be rolled or opened to traffic as directed. Th tractor, as often as directed, shall work and dress the surface so that the section shall continue uniform and true to line and grade until accepted

35.6. The work shall be rolled or opened to traffic as directed. Th tractor, as often as directed, shall work and dress the surface so th cross-section shall continue uniform and true to line and grade until acc

35.6. **Method of Measurement.**—Work and accepted material sh measured by the cubic yard of material, loose measurement, as del on the road.

35.7. **Basis of Payment.**—When a unit price for Caliche is request tendered in the proposal, the material furnished as prescribed by thi shall be paid for at the contract unit price so bid per cubic yard. such price is not so requested, right-of-way charges and royalties material in the pit will not be a charge to the contractor. The wo formed as prescribed for this item, measured as provided above, sl paid for at the contract unit price bid per cubic yard for Caliche Base (which price shall be full compensation for loading all material, hauli over ¼ mile, delivering on the road, puddling and finishing, all labor, ment, tools and incidentals necessary to complete the work except r and sprinkling. Hauling material into each quarter mile beyond th quarter mile shall be paid for at the contract unit price per cubic yard Material Hauled Additional Quarter Mile.

Item 36. Disintegrated Limestone Base Course[1]

36.1. **Description.**—This item shall consist of a foundation cou surface courses or other base courses, shall be composed of disinte limestone, and shall be constructed on the prepared subgrade in acco with these specifications and in conformity with the lines, grades, com thickness, number of component courses, and typical cross-section sho plans.

36.2. **Materials.**—The material shall consist of a good quality of d grated limestone, reasonably free from soil and clay, and when loade the material pit shall not contain more than 25% of material whi pass a ¼″ mesh screen. The disintegrated limestone shall be such be loosened up in the pit by the use of plows or picks and without the explosives. Material containing gravel or hard flint pebbles will be adr although all hard stones over 3½″ in their largest dimension, whi not be broken up by traffic or rolling, must be thrown out at the pit contractor at his own expense.

36.3. **Construction Methods.**—The material shall be delivered and by hand on the prepared subgrade to such depth that when com the thickness shown on the plans will be secured, and shaped to conf the typical cross-section. Side forms and either cubical blocks or guide forms of proper size shall be used to fix the depth of the loose ma It shall, be the charge of the contractor that the required amount of m shall be delivered in each 100′ station and uniformly distributed throu each station.

[1] Texas.

. After the material has been spread and shaped, the surface shall be ighly sprinkled with water and rolled as soon as sufficiently dried off. ontractor, as often as directed, shall work and dress the surface so that oss-section shall continue uniform and true to line and grade until ed. When the typical cross-section requires that this item be con- ed in more than one course, each additional course shall be constructed ndently after the previous one has been completed and accepted, all scribed above.

. **Method of Measurement.**—Work and accepted material hauled to d shall be measured by the cubic yard of material, loose measurement, vered on the road.

. **Basis of Payment.**—When a unit price for Disintegrated Limestone ested and tendered in the proposal, the material furnished as prescribed s item shall be paid for at the contract unit price so bid per cubic yard. such price is not so requested, right-of-way charges and royalties on aterial in the pit will not be a charge to the contractor. The work med as prescribed for this item, measured as provided above, shall be or at the contract unit price bid per cubic yard for Disintegrated Base , which price shall be full compensation for loosening and loading all al at the pit, hauling not over ¼ mile, delivering on the road, puddling inishing, all labor, equipment, tools, and incidentals necessary to ete the work except rolling, and sprinkling. Hauling material into uarter mile beyond the first quarter mile shall be paid for at the con- nit price bid per cubic yard for Material Hauled Additional Quarter

Item 37. Iron-ore Topsoil Base Course[1]

. **Description.**—This item shall consist of a foundation course for courses or other base courses, shall be composed of iron-ore topsoil, all be constructed on the prepared subgrade in accordance with these cations and in conformity with the lines, grades, compacted thickness, r of component courses, and typical cross-section shown on plans.

. **Materials.**—Iron-ore topsoil shall consist of hematite, hydrated ite, or limonite ore as found at the surface but of a quality free from ble matter which, when loaded from the material pit, shall not contain than 15% of clay. The material shall be such as can be loosened up in t by the use of plows or picks and without the use of explosives. ial containing gravel or hard pieces of ore will be admitted, although ces over 3½″ in their largest dimension, which will not be broken up construction, must be thrown out at the pit by the contractor at his pense. The material shall have a cementing value of not less than 50 so graded that 40 to 75% is retained on a 10-mesh screen when tested oratory methods.

. **Construction Methods.**—The material shall be delivered and spread d on the prepared subgrade to such depth that when compacted the ess shown on the plans will be secured and shaped to conform to the l cross-section, and rolled if required. Side forms and either cubical or center guide forms of proper size shall be used to fix the depth of se material. It shall be the charge of the contractor that the required t of material shall be delivered in each 100′ station and uniformly uted throughout each station.

. After the material has been spread and shaped, the work shall be or opened to traffic as directed. If the material is of such a quality adheres to the wheels of the roller after sprinkling, the surface shall ded, the necessary material being measured as surfacing material. ntractor, as often as directed, shall work and dress the surface so that oss-section shall continue uniform and true to line and grade until ed. When the typical cross-section requires that this item be con- ed in more than one course, each additional course shall be constructed ndently after the previous one has been completed and accepted, all scribed above.

. **Method of Measurement.**—Work and accepted material hauled to d shall be measured by the cubic yard, loose measurement, as delivered road.

. **Basis of Payment.**—When a unit price for Iron-ore Topsoil is ted and tendered in the proposal, the material furnished as prescribed item shall be paid for at the contract unit price so bid per cubic yard. such price is not so requested, right-of-way charges and royalties on

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the material in the pit will not be a charge to the contractor. The performed as prescribed for this item, measured as provided above, sh paid for at the contract unit price bid per cubic yard for Iron-ore T Base Course, which price shall be full compensation for loosening and lo all material at the pit, hauling not over ¼ mile, delivering on the finishing, all labor, equipment, tools, and incidentals necessary to com the work except rolling, and sprinkling. Hauling material into each qu mile beyond the first quarter mile shall be paid for at the contract unit bid per cubic yard for Material Hauled Additional Quarter Mile.

Item 38. Gravel Base Course[1]

38.1. **Description.**—This item shall consist of a foundation cours surface courses or for other base courses, shall be composed of gravel shall be constructed on the prepared subgrade in accordance with specifications, and in conformity with the lines, grades, compacted thic number of component courses, and typical cross-section shown on the

38.2. **Materials.**—The gravel shall consist of hard durable partic stone mixed with sand or clay or other similar binding material and tested by laboratory methods shall fulfil the following requirements:

Retained on 3½″ screen	0– 5
Retained on ¼″ screen	50–75

38.3. Of the material retained on the ¼″ screen, 50 to 75% sh retained on the ¾″ screen.

38.4. The material passing the ¼″ screen shall be known as "bi and of this material 15 to 35 % shall pass the 200-mesh sieve. The ceme value of the binder shall be not less than 50.

38.5. The gravel may be crushed or uncrushed, and may be bank r the binder may be added and incorporated by approved methods as h after specified.

38.6. **Construction Methods.**—The material shall be delivered in bottom wagons or approved trucks and uniformly dumped on the sub or completed course, spread to such depth that, when compacted, the ness shown on the plans will be secured, harrowed if necessary, and sha conform to the typical cross-section. Each day's hauling shall be s the same day. When the width of the course is more than 12′ the m shall be dumped in two equal rows. The thickness of the course as the material shall be strictly uniform. Side forms, and either center or cubical blocks, shall be used to fix the depth of loose material. All and "nests" of segregated coarse or fine material shall be remove replaced with well-graded material and compacted.

38.7. If the gravel is deficient in binder as prescribed under Ma above, after it is spread and shaped, additional binder shall be furnish applied in the amount directed by the engineer so as to comply wi grading requirements. Such binder shall be measured and paid provided for the normal gravel, and shall be carefully and evenly incorp with the material in place as directed by the engineer.

38.8. The work shall be rolled and sprinkled, or opened to traffic as dir Ruts shall be kept filled twice a day or more as directed. When irregul depressions, or weak spots develop during the process of shaping and s up, the affected areas shall be corrected immediately by scarifying, a material as needed, reshaping, and compacting. This process sh continued, and the course maintained with grading machines or equipment as required, to the required line, grade, and typical cross-s until the surface is smooth and hard, free from ruts and undulation bonded to the width shown on plans, and the work is accepted.

38.9. When the typical cross-section requires that this item be const in more than one course, each course shall be constructed indepen after the previous one is completed and accepted, all as prescribed ab

38.10. **Method of Measurement.**—Work and accepted material sh measured by the cubic yard of material, loose measurement, as delive the road.

38.11. **Basis of Payment.**—When a unit price for Gravel for Base is requested and tendered in the proposal, the material furnished a scribed for this item shall be paid for at the contract unit price so bid; price shall include all pit charges, crushing, screening, and freight

[1] Texas.

y points. When such price is not requested the material will be ned free of royalty and right-of-way charges, and the contractor will d for all Crushing and Screening or Screening as ordered, at the prices r cubic yard for Crushing and Screening or for Screening.

2. The work performed as prescribed for this item, measured as pro- under Measurement, shall be paid for at the contract unit price bid per yard for Gravel Base Course, which price shall be full compensation ding all material, hauling not over ¼ mile, delivering on the road, ing and finishing, all labor, equipment, tools, and incidentals necessary nplete the work except crushing, screening, rolling, and sprinkling. ng into each quarter mile beyond the first quarter mile shall be paid for contract unit price bid per cubic yard for Material Hauled Additional r Mile.

Item 39. Soft Limestone Base Course[1]

. **Description.**—This item shall consist of a foundation course for courses, or for other base courses, shall be composed of large fragments local limestone wedged in place with small stones and spalls and leveled h smaller stone and binder, and shall be constructed on the prepared de in accordance with these specifications, and in conformity with the grades, and typical cross-sections shown on the plans.

. **Material.**—The limestone shall be the best obtainable in the local ee from soapstone or similar material and with a per cent of wear of ore than 12. The stones shall be no larger than 12″ in their largest sion. The broken stone shall be of a size to pass the 3½″ screen. nder shall be screenings, gravel, caliche, or other approved material shall pass the ¾″ screen.

. **Construction Methods.**—The large stone shall be dumped and spread he prepared subgrade, and broken with sledges until there are no stones he top of the course larger than 6″. When the sledging has been d, the surface shall be rearranged to insure uniform distribution of the al, the larger voids filled with spalls, and the course rolled. The shall then be bonded with sufficient crushed stone and binder to superficial voids, and the course finished to conform to the line, grade, pical cross-section.

. The rolling shall be as prescribed under Extra Rolling and Sprinkling se Courses, and the surface shall be sprinkled if ordered by the engineer. regularities that develop during or after rolling shall be remedied by ng, adding or removing material and rebonding. The surface shall be ined in its finished condition until accepted.

. **Method of Measurement.**—Work and accepted material shall be red by the cubic yard of material, loose measurement, as delivered road.

. **Basis of Payment.**—When a unit price for Local Base Course Lime- s requested and tendered in the proposal, the material furnished as bed for this item shall be paid for at the contract unit price so bid. such price is not so requested, right-of-way charges and royalties on terial in the pit will not be a charge to the contractor.

. The work performed as prescribed for this item, measured as pro- under Measurement, shall be paid for at the contract unit price bid bic yard for Soft Limestone Base Course, which price shall be full nsation for loading all material, hauling not over ¼ mile, delivering road, spreading, and finishing, all labor, equipment, tools, and inciden- cessary to complete the work, except rolling and sprinkling. Hauling ch quarter mile beyond the first quarter mile shall be paid for at the ct unit price bid per cubic yard for Material Hauled Additional Quarter

Item 40. Sledged-stone Base Course[1]

Description.—This item shall consist of a foundation course for courses, or for other base courses, shall be composed of large stones l in place by small stones and spalls and leveled up with broken stone nder, and shall be constructed on the prepared subgrade in accordance nese specifications, and in conformity with the lines, grades, and typical ection shown on plans.

Material.—The stone shall be a good grade of limestone or sandstone, m excess of shell, soapstone, or other similar material with a per cent r of not over 8. Thin stones which break into slabs shall not be used.

[1] xas.

The stones shall not be over 12″ in their largest dimension. The b stone shall be of a size to pass the 3½″ screen. The binder shall be s ings, gravel, caliche, or other approved material which shall pass th screen.

40.3. Construction Methods.—The large stone shall be dumped and s upon the prepared subgrade, and broken with sledges until there a stones near the top of the course larger than 6″. When the sledgir been finished, the surface shall be rearranged to insure uniform distril of the material, the larger voids filled with the spalls, and the course The surface shall then be bonded with sufficient crushed stone and l to fill the superficial voids, and the course finished to conform to th grade, and typical cross-section.

40.4. The rolling shall be as prescribed under Extra Rolling and Spri for Base Courses, and the surface shall be sprinkled if ordered by the en Any irregularities that develop during or after rolling shall be rer by loosening, adding or removing material, and rebonding. The s shall be maintained in its finished condition until accepted.

40.5. Method of Measurement.—Work and accepted material sh measured by the cubic yard of material, loose measurement, as delive the road.

40.6. Basis of Payment.—When a unit price for Sledging Stone is req and tendered in the proposal, the material furnished as prescribed f item shall be paid for at the contract unit price so bid. When such p not so requested, right-of-way charges and royalties on the mate the pit will not be a charge to the contractor.

40.7. The work performed as precribed for this item, measured a vided under Measurement, shall be paid for at the contract unit pri per cubic yard for Sledged-stone Base Course, which price shall l compensation for loading all material, hauling not over ¼ mile, delive the road, spreading and finishing, all labor, equipment, tools, and incic necessary to complete the work except rolling, and sprinkling. H into each quarter mile beyond the first quarter mile shall be paid for contract unit price bid per cubic yard for Material Hauled Additional Q Mile.

Item 41. Crusher-run Broken-stone Base Course[1]

41.1 Description.—This item shall consist of a foundation cou surface courses, or other base courses, shall be composed of crushe and screenings as the material comes from the crusher, and shall b structed on the prepared subgrade, or other completed base course, in a ance with these specifications, and in conformity with the lines, g compacted thickness, number of component courses, and typical cross- shown on the plans.

41.2. Material.—The stone shall not contain more than 5 % of pa decomposed particles, and not more than 5 % of flat or elongated piec width of which is less than half the length. The material may be unsc or partially screened, but when tested by laboratory methods the stor meet the following requirements:

Retained on the 3½″ screen....	0 to 5
Retained on the 2″ screen..........................	25 to 60
Retained on the ¼″ screen..........................	95 to 100

41.3. Screenings for additional binder shall be the product from stone which shall meet the following requirements:

Retained on the 1″ screen..........................	0 to 5
Retained on the 14″ screen..........................	20 to 60

41.4. Construction Methods.—The subgrade shall be rolled. The shall be delivered in slat-bottom wagons or approved trucks, and uni dumped on the subgrade, spread to such a depth that when compact thickness shown on the plans will be secured, shaped to conform to the cross-section, and rolled. The subgrade shall be thoroughly dry wh material is delivered; each day's hauling shall be spread the sam When the width of base course is more than 12′ the material shall be d in two equal rows. The thickness of the course as well as the materi be strictly uniform. Side forms, and either center forms or cubical shall be used to fix the depth of loose material. All areas and "ne

[1] Texas.

ated coarse or fine material shall be removed and replaced with well-
d material and rerolled if necessary.
5. The rolling shall be as prescribed under Extra Rolling and Sprinkling and Surface Courses. After thorough rolling, and if found necessary, ings shall be spread with shovels in a uniform layer. The screenings not be dumped directly on the surface of the coarse stone. The shall be further rolled and sprinkled if ordered by the engineer, the e shall be thoroughly bonded to his satisfaction, and finished to con- to the line, grade, and typical cross-section.
). If any irregularities develop in the surface during or after rolling, they be remedied by loosening, adding or removing material, and rebonding. urface shall be maintained in its finished condition until accepted.
7. If at any time the subgrade material should become churned up or with the base course, the contractor, without additional compensation, lig out and remove such mixture, reshape and compact the subgrade, construct the base course with new material.
3. When the typical cross-section requires that this item be built in than one course, each course shall be constucted independently after evious one is completed and accepted, all as prescribed above.
). **Method of Measurement.**—Work and accepted material shall be red by the cubic yard of material loose measurement, as delivered on ad.
o. **Basis of Payment.**—The material furnished as prescribed by this hall be paid for at the contract unit price per cubic yard for Crusher- roken Stone, which price shall also be full compensation for quarrying, ng, and screening, and freight involved. The work performed as ibed for this item, measured as provided above, shall be paid for at the ct unit price per cubic yard bid for Crusher-run Broken-stone Base e, which price shall be full compensation for loading all material, g not over ¼ mile, delivering on the road, spreading and finishing, all equipment, tools, and incidentals necessary to complete the work rolling, and sprinkling. Hauling material into each additional quarter eyond the first quarter mile shall be paid for at the contract unit price bic yard bid for Material Hauled Additional Quarter Mile.

42. Water-bound Gravel or Broken-stone Macadam Base Course[1]

. **Description.**—This item shall consist of a foundation course for e courses or pavements, shall be composed of washed gravel or broken and binder, and shall be constructed on the prepared subgrade or other eted base course in accordance with these specifications, and in con- y with the lines, grades, compacted thickness, and typical cross-section on the plans.
. **Material.**—The broken stone shall consist of angular fragments of excluding schist shale or slate) of uniform quality throughout, with not han 5 % of soft friable material, not more than 5 % of flat or elongated the width of which is less than half the length, and with a per cent of of not more than 8. When tested by laboratory methods the stone neet the following requirements:

etained on 3½″ screen	0– 5 %
etained on 2 ″screen	25–60 %
etained on ¾″ screen	100 %

. The washed gravel shall consist of rounded or angular fragments of vith nor more than 5 % of slate, shale,or soft sandstone particles, and be free from organic matter, clay, loam, or pebbles coated therewith. y be crushed or uncrushed, and shall have a per cent of wear (abrasion r gravel) of not more than 18. When tested by laboratory methods l meet the following requirements:

etained on 3½″ screen	9– 5 %
etained on 1½″ screen	25– 60 %
etained on ½″ screen	95–100 %

. Screenings shall consist of material equal in quality to that specified oken Stone above, and shall be that product of the crusher, including st of fracture, which will meet the following requirements:

etained on ¾″ screen	0– 5 %
etained on ¼″ screen	20–60 %
assing 200-mesh sieve	5–20 %

[1] xas.

42.5. **Construction Methods.**—The subgrade shall be rolled and sh
dry and clean of all foreign substances. The stone or gravel shall b
nished, spread upon it to such loose depth that when completed the
pacted depth shown on plans will be obtained, harrowed if necessary, s
to the typical cross-section, and dry rolled. The stone shall be spread
shovels from storage piles along the side of the roadway or from dur
boards or may be spread directly from approved vehicles. The gravel
be dumped in two equal rows and shaped by grading machine or road
provided it is shaped the same day it is dumped. The thickness of the c
as well as the material, shall be strictly uniform. Side forms, and
center forms or cubical blocks, shall be used to fix the depth of loose ma
The shoulders shall be built up to support the edges of the course as dir
All areas and "nests" of segregated coarse or fine material shall be ren
and replaced with well-graded material.

42.6. The dry rolling shall be done with a self-propelled roller wei
not less than 8 tons. The rolling shall be longitudinal, shall begin a
sides, overlapping the earth shoulders at least 6″, and progress grad
to the center. At any low places that develop the material shall be loo
and the necessary additional material placed and rerolled. The
surface shall be thoroughly rolled until all settlement has ceased.

42.7. Screenings shall be applied gradually over the surface durin
dry rolling in such an amount as will completely fill the interstices.
screenings shall not be dumped on the surface of the stone or gravel, bu
be cast thinly with a spreading motion of the shovel and broomed in
voids. The rolling shall continue while the screenings are being spre
as to aid by jarring the fine material into the interstices. The scre
shall not be allowed to cake or "bridge" on the surface so as to preve
filling of the voids or the direct bearing of the roller on the surface
stone or gravel. The spreading and rolling shall continue until no
screenings will go in dry and the whole surface conforms to the line,
and typical cross-section. No excess screenings shall be used.

42.8. Dumping of ashes and cinders from the firebox on the course
not be allowed and any litter must be removed from the stone or
before the roller passes over it.

42.9. After the dry rolling and filling is complete, the surface of the
shall be sprinkled with water until thoroughly saturated and more scre
added and rolled. The sprinkling and rolling shall continue until a
forms in front of the roller that will fill all voids. The work shall th
permitted partially to dry out, and the rolling shall be continued on s
sive days until the bond is complete and the surface does not creep or
under the roller. The surface of the course shall be maintained in its fi
condition until accepted.

42.10. **Method of Measurement.**—The work completed and ac
shall be measured by the square yard.

42.11. **Basis of Payment.**—All work performed under this item and
ured as provided above shall be paid for at the contract unit price per s
yard bid for Water-bound Gravel or Broken-stone Macadam Base C
which price shall be full compensation for purchasing, furnishing, quar
screening, hauling and delivering on the road, and rolling all materia
all labor, equipment, tools, and incidentals necessary to comple
work. No overhaul will be allowed.

BOTTOM COURSE

Item 43. Bottom Course, Screened Gravel; Item 44. Bottom Co Broken Slag; Item 45. Bottom Course, Broken Stone[1]

a. **Work.**—Under these items the contractor shall furnish and place
slag, or gravel, conforming to the general requirements for same,
upon the properly prepared subgrade or upon the foundation course.
stone, slag, or gravel shall be of sizes specified below.

b. **Material.**—After the subgrade or foundation course shall have
properly prepared and proper drainage provided, a course of broken
broken slag, or gravel of graded No. 4 or a uniform mixture of Nos. 3
shall be spread evenly so that it will have, after rolling, the required thic

In cases where the finished thickness of the bottom course is of
than 5″ the broken stone, broken slag, or gravel for it shall be spread,

[1] New York.

filled in two separate layers, neither of which shall be of a greater depth 1 6″ measured loose.

Gaging Blocks.—The depth of loose stone, slag, or gravel in all cases l be gaged by the use of cubical blocks of suitable size.

Dumping on Roadway.—The spreading of any layer or course of broken .e, broken slag, gravel, or filler, whether in foundation, bottom, or top rses, shall be done from suitable spreader wagons or from piles dumped g the road as directed by the engineer.

o segregation of large or fine particles will be allowed, but the stone, , or gravel as spread shall be well graded with no pockets of fine material.

Rolling and Filling.—After the bottom course of stone, slag, or gravel been laid loose it shall be thoroughly rolled with an approved roller ghing not less than 10 tons.

his rolling must begin at the sides and continue toward the center and l continue until there is no movement of the course ahead of the roller. r the course is thoroughly compacted, No. 1 stone, slag, or gravel, and enings or sand, or a mixture of these, shall be uniformly spread upon the ace and swept in with rattan or steel brooms and rolled dry. After the pletion of the rolling no teaming other than that necessary for bringing erial for the next course shall be allowed over the rolled material. It is intention to bind this course with the small stone or slag, but no surplus ller will be allowed on this course. This course shall not be laid in ss of 500 lin. ft. without being rolled and thoroughly filled so as to render aterproof and thereby prevent the softening up of the subgrade.

In Case of Two Courses.—When two courses are laid each course shall reated by rolling and adding fine material as described above.

Replacing.—If the subgrade material shall become churned up into or ed with the bottom or subbottom courses through the contractor's ing over it or working on it when the subgrade is in a wet condition, contractor shall at his own expense remove such mixture of subgrade erial and broken stone, broken slag, or gravel and replace it with clean en stone, broken slag, or gravel of the proper size, and shall roll or other- compact the material so as to produce a uniform, firm, and even bottom se.

the above condition occurs through no fault of the contractor, the ractor shall be paid both for excavating and replacing under the items avation and Bottom Course respectively.

Piles of Filler.—All filler shall be delivered and piled alongside the road re the course in which it is to be used is placed.

Measurement and Payment.—The quantity to be paid for under these s respectively shall be the number of cubic yards of compacted material lace in the completed course. The amount to be estimated shall be puted by multiplying the finished cross-section of bottom course, as vn upon the plans or ordered by the engineer, by the length of the om course measured along the axis of the pavement.

he price bid for the respective items shall cover the furnishing, placing, g, rolling of the material, and all labor and incidental expenses necessary omplete the work.

Item 50. Binder Course, Bituminous Macadam, Mixing Method[1]

Work.—Under this item the contractor shall construct a bituminous er course of the thickness shown on the plans, consisting of compact en stone and bituminous material upon a previously prepared founda- . It shall be laid in conformity with the lines and grades shown upon the s or ordered by the engineer. A smooth finish will be insisted upon, from irregularities and waviness.

Material and Method.—The broken stone used in this course shall be of pted material of No. 1 size.

The mineral aggregate for the binder course shall be heated in revolving ers to between 225 and 300°F. The mineral aggregate shall be con- ously agitated during the heating.

The bituminous material to be used in this course shall conform to the ifications for bituminous material A, type 2.

The bituminous material A shall be heated in kettles so designed as to it of an even heating of the entire mass, with an efficient control of the at all times. The bituminous material shall be heated to a temperature een 275 and 325°F. All material heated above 325°F. either before or

[1] New York.

during mixing with the broken stone, or which has been damaged by lo continued heating, shall be rejected. No asphalt cement shall be heate kettles containing tar.

f. When thoroughly heated to the proper temperatures, the bitumin material and the mineral aggregate for the binder course shall be mixe such proportions as to give from 5 to 8 % by weight of bitumen in the c pleted mixture. The contractor shall provide means for accurately pro tioning the mixture. The mixer shall be of satisfactory design, ha revolving blades and efficient means for keeping the temperature at desired point without burning the bitumen. The mixing shall conti until every particle of the mineral aggregate is thoroughly coated with bituminous material and a uniform mixture has been obtained, which w discharged shall have a temperature between 225 and 300°F.

g. The use of batteries of small batch mixers will not be allowed.

h. The bituminous mixture, heated and prepared as specified above, s be delivered from the mixer to the point of deposition in the pavem if at a considerable distance, in suitable trucks or wagons, provided canvas covers for retaining the heat. To prevent undue compacting long hauls, partitions may be required for large truck loads. As delive the mixture shall have a temperature of at least 200°F. Material havi lower temperature than this shall not be laid in the pavement. Before mixture is placed, all contact surfaces of curbs, edging manholes, etc., s be well painted with hot bituminous material. The mixture shall be im diately spread over the foundation course by men experienced in such w so that when rolled it shall have the required thickness and shall be from surface depressions and irregularities. The hot paving mixture s not be dumped in large masses upon the foundation. It shall be dumped u platforms and shoveled with hot shovels into position in the pavement.

i. The binder course, placed as above specified, shall be compressed hot hand tamps along the curbs, around manholes, and other edgings. shall be rolled at once while the material is still warm and pliable, begin at the edges and working toward the center. The roller wheels shal swabbed with crude oil to prevent the asphalt from sticking to the ro Rolling shall continue without interruption until all roller marks disap and the surface shows no further compressibility. All places which roller cannot effectively reach shall be compresed with hot tamps.

j. The finished surface of the binder course shall be tested with a straight-edge laid parallel with the center line of the pavement, upon portion of the surface, and any depressions exceeding ½″ shall be s factorily eliminated or the course relaid.

k. No more binder course shall be laid at any one time than can be cov by 2 days' run of the paving plant on surface mixture.

l. **Roller.**—Rollers used for the binder course shall be well-balanced, propelled tandem rollers of satisfactory design, weighing between 7 a tons. They shall give a compression under the rear roller of between and 300 lb. per lineal inch of roll, and shall be provided with an ash pan w shall prevent ashes from dropping upon the pavement.

m. The contractor shall provide a sufficient number of accurate effi thermometers for determining the temperatures of the bituminous mat and mineral aggregate at all stages of the work.

n. **Measurement and Payment.**—The quantity to be paid for under item shall be the number of tons of material incorporated in the paven exclusive of the bituminous material, as shown on the plans or directe the engineer.

The price bid shall cover the furnishing (bituminous material excep heating, placing, rolling, and compacting of all materials, together wit other labor and incidental expenses necessary to complete the satisfactorily.

The furnishing of the bituminous material will be paid for under appropriate item, therefore, as shown on the proposal sheet.

Item 43. Bituminous-concrete Base Course[1]

43.1. Description.—This item shall consist of a bituminous-con foundation course for bituminous surface courses or pavements, shal composed of coarse and fine mineral aggregate and bituminous cen and shall be constructed on the prepared subgrade or completed base cc in accordance with these specifications and in conformity with the l grades, compacted thickness, and typical cross-section shown on the pla

[1] Texas.

3.2. **Material.**—The mineral aggregate for the mixture shall consist of a rse aggregate of crushed stone or gravel, and a fine aggregate. Samples the coarse and fine aggregate shall be submitted in accordance with ndard prescribed methods, and approval both of the material and of the rce of supply shall be obtained from the engineer, prior to delivery of erial. Material shipped in dirty cars or vehicles will be rejected. The rse aggregate shall consist of clean, tough, durable fragments of rock cluding schist, shale, or slate) of uniform quality throughout, shall be from an excess of thin or elongated pieces, and free from soft or disintegted stone, dirt, organic, or other injurious matter occurring either free s a coating on the stone. The aggregate shall have a per cent of wear ot more than 7 for stone and not more than 15 for gravel (abrasion test gravel) and when tested by laboratory methods shall meet the following uirements:

Passing $2\frac{1}{2}''$ screen	100 %
Passing $1\frac{1}{4}''$ screen	25–75 %

3.3. The fine aggregate shall consist of sand or a combination of sand screenings, composed of hard durable grains free from clay organic tter or any soft or injurious material. When tested by laboratory hods, it shall meet the following requirements:

Passing	Retained on	%
$\frac{1}{4}''$ screen		100
$\frac{1}{4}''$ screen	10-mesh sieve	0–20
10	40	15–50
40	80	25–65
80	200	7–40
200		9–6

3.4. The bituminous material shall meet the requirements given below OA-7, NA-7, or NA-9. The material shall be homogeneous, free from er, and the asphalt material shall not foam when heated to 175°C. 7°F.). Oil asphalt for any one contract shall not vary more than 0.020 specific gravity nor more than 10°C. in melting point within the test its above specified.

3.5. OA-7. Oil asphalt.

cific gravity 25°/25°C. (77°/77°F.)....Not less than 1.020
sh point....Not less than 175°C. (347°F.)
lting point....45°C. (113°F.)–65°C. (149°F.)
etration at 25°C. (77°F.), 100 g., 5 sec....40–50
s at 163°C. (325°F.), 5 hr....Not more than 1.0 %

Penetration of residue at 25°C. (77°F.), 100 g., 5 sec....Not less than 25
Total bitumen (soluble in carbon disulphide), not less than 99.5 %.
Organic matter insoluble....Not more than 0.2 %

3.6. NA-7. Fluxed Bermudez asphalt.

cific gravity 25°/25°C. (77°/77°F.)....1.055–1.075
sh point....Not less than 175°C. (347°F.)
lting point....45°C. (113°F.)–55°C. (131°F.)
etration at 25°C. (77°F.), 100 g., 5 sec....40–50
s at 163°C. (325°F.), 5 hr....Not more than 3.0 %

Penetration of residue at 25°C. (77°F.), 100 g., 5 sec....Not less than 20
Total bitumen (soluble in carbon disulphide), not less than 94.0 %.
Inorganic matter insoluble....2.5–4.0 %

3.7. NA-9. Fluxed Trinidad asphalt.

cific gravity 25°/25°C. (77°/77°F.)....1.210–1.270
sh point....Not less than 175°C. (347°F.)
lting point....50°C. (122°F.)–60°C. (140°F.)
etration at 25°C. (77°F.), 100 g., 5 sec....40–50
s at 163°C. (325°F.), 5 hr....Not more than 3.0 %

Penetration of residue at 25°C. (77°F.), 100 g., 5 sec....Not less than 20
Total bitumen (soluble in carbon disulphide), not less than 65.0 %.
Inorganic matter insoluble....22.0–32.0 %

3.8. **Proportions of Materials in Total Mixture.**—In addition to the vious requirements, the coarse aggregate, fine aggregate, and bituminous

material shall be so graded and proportioned by weight that when combi a total mixture of the following proportions will be secured:

Passing	Retained on	% by Weight
2½" screen	1¼" screen	20–45 } 50
1½" screen	¼" screen	15–45 }
¼" screen	10-mesh sieve	10–25
10-mesh		15–35
200		3– 5

Bitumen (soluble in carbon disulphide), 4–7 %.

43.9. The proportions shall be varied within the limits designated directed by the engineer, but neither the type nor proportions of mate shall be varied without the consent of the engineer. The percentage bitumen in the finished base course shall not vary more than one-half of from the proportion established by the engineer. Unvarying uniformit of prime importance and both the proportioning and treatment of all ma rials must be maintained consistently satisfactory to the engineer through the construction period, and, whenever required by him, samples of the mixture may be taken several times daily, and the mixture, to be accepta must invariably conform to all requirements.

43.10. **Preparation of Mineral Aggregate.**—The coarse and fine aggreg shall be heated as directed to between 250 to 350°F. in suitable apparatu which the aggregate shall be continuously agitated during the heating an which the temperature can be efficiently and positively controlled.

43.11. The bituminous material shall be separately heated, with effec control of the temperature at all times, to between 250 and 350°F. material heated above 350°F. either before or during the mixing with mineral aggregate shall be rejected.

43.12. **Mixing.**—The constituent proportions of the mineral aggreg shall be measured separately and accurately by weight or volume by accu plant methods which meet the engineer's specific written approval. required quantity of hot bituminous material for each batch shall be meas by actual weighing with accurate scales attached to the bucket. measuring and proportioning shall be such as to secure accurately and sistently the graded mixture prescribed by these specifications. Bat shall be uniform and shall not be varied except by direction of the engin The mixing shall be done in an approved batch mixer, which shall be desig and operated as to produce and discharge a uniform mixture of thorou coated mineral aggregate and bituminous material as prescribed. heated bituminous material shall be introduced in the mixing chamber a the mineral aggregate has been previously mixed therein. The mixtur discharged shall be at a temperature between 250 and 350°F., and shall vary more than 30° from the temperature set by the engineer within th limits. The plant must be provided with separate heating and mixing ch bers, no direct heat except steam shall be applied to the exterior surfac the mixing chamber, and no flame shall be allowed to pass through the mi chamber.

43.13. **Placing.**—The prepared mixture shall be transported from mixing plant to the road in tight vehicles previously cleaned of all for materials, and shall be delivered on the road at a temperature between and 350°F. If required by engineer, the loads shall be protected from weather by canvas, or other suitable material. No loads shall be sent ou late in the day as to prevent spreading and rolling the mixture during light, unless artificial light satisfactory to the engineer is provided. work shall be done only when weather conditions, in the opinion of engineer, are suitable.

43.14. Prior to the arrival of the hot mixture upon the work, the subgr having been rolled, shall be thoroughly bonded with no loose or for particles on its surface, and shall be dry, or in any case free from stan water. Contact surfaces of curbs, gutters, manholes, etc., shall be pai with a thin uniform coat of hot asphaltic cement, or asphaltic cem dissolved in naphtha, just before the surface mixture is placed against th Upon arrival at the work, the hot mixture shall be dumped on appro steel "dump boards" outside of the area upon which it is to be spread, immediately distributed into place by means of hot shovels and spread w hot rakes in a uniformly loose layer of such depth that when compac the depth shown on the typical cross-section will be obtained. Adjacen flush curbs, gutters, etc., the mixture shall be raked uniformly high, so t

l be slightly above the edge of the curb or flush structure. The mixture be rolled at once while it is still warm and pliable, beginning at the and working toward the center. The rolling shall be done by tandem s weighing not less than 8 tons, or by a similar tandem roller and a -wheeled roller weighing not less than 10 tons. Means for preventing ituminous material from adhering to the roller shall be provided as ed by the engineer. The rolling shall progress continuously at the f not more than 200 sq. yd. per hour per roller and shall include longitu- rolling and two diagonal rollings approximately at right angles to each . The motion of the rollers shall be at all times slow enough to avoid cement of the hot mixture or any tendency to the creation of waves, hall be continued until all roller marks disappear and the course has a y of not less than 95 % of its maximum calculated density. For a distance of 8″ around all structures and all places inaccessible to the s, compression shall be effected by hot iron tampers of bearing area of in. or more, and weight of not less than 25 lb.

415. **Joints.**—Placing of the base course shall be as nearly continuous as ble, and the roller shall pass over the unprotected end of the freshly nixture only when the laying of the course is discontinued for such of time as to permit the mixture to become chilled. In all such cases the work is resumed the material laid shall be cut back so as to produce ntly beveled edge for the full thickness of the course. The old material has been cut away shall be removed from the work and new mix laid st the fresh cut. If desired, a stout rope may be stretched across the nent where the joint is to be made. When the work is resumed, the ial laid shall be cut back to the rope, which will be removed together he surplus material and the fresh mix laid against the joint thus formed. moothing irons may be used for sealing joints, but in such case extreme hall be exercised to avoid burning the surface.

416. **Surface Finish and Tests.**—The surface of the mixture after rolling be smooth, dense, and true to the established crown and grade. Before ompletion of the rolling the surface shall be tested as follows, and ted as necessary by properly adding or removing hot mixture, retesting, rolling until the finished surface complies with the test requirements.

417. **Surface Tests.**—The finished course shall show no deviation from neral surface in excess of ¼″ as shown by deviation from a 10′ straight- aid parallel to the center line of the road so as to bridge any depressions ouch all high spots.

418. Such portions of the course as are defective in finish, density, or osition or become loose, broken, or mixed with dirt prior to the applica- of the wearing surface shall be removed and replaced with fresh hot re and rebuilt in accordance with these specifications at the expense of ontractor. The base course shall be protected from traffic until cold.

419. The surface shall be maintained in its finished condition until cted.

420. **Method of Measurement.**—This item shall be measured by the yard complete in place.

421. **Basis of Payment.**—The yardage of completed and accepted work ured as provided above shall be paid for at the contract unit price bid quareyard, for Bituminous Concrete Base Course, which price shall ll compensation for quarrying, furnishing, hauling, and placing all ial, for preparaion of all material, for all labor, equipment, tools, and ntals necessary to complete the work.

Foundation Type C

74A. PORTLAND CEMENT CONCRETE

MPOSITION.

s foundation shall be prepared from concrete having the following osition: Portland cement one (1) bag, fine aggregate three (3) cubic oarse aggregate five (5) cubic feet by volume, unless the character of the ate is such that the specified quantity of cement required per cubic s not secured. In such cases, the ratio of cement to fine aggregate or aggregate to coarse aggregate, shall be changed as herein provided t the specified quantity of cement will be secured per cubic yard of ete. The Contractor will receive no additional compensation for g such changes.

ncrete headers, when integral with the foundation, shall be constructed same aggregate used in the foundation, but shall have the following

composition: Portland cement, one (1) bag; fine aggregate, two (2) feet; coarse aggregate, four (4) cubic feet.

2. MATERIALS REQUIRED.

Cement—The cement shall meet the requirements given in Article 9

Fine Aggregate—The fine aggregate shall be concrete sand as defin Article 95b.

Coarse Aggregate—The coarse aggregate shall be trap rock, dolomi ...., concrete size or grade as specified in Articles 92 inclusive.

Cement and Aggregate—Before any orders are placed or deliveries r the Contractor shall obtain the Engineer's written approval of the ce fine and coarse aggregates he intends to use. In making requests fo approval, the Contractor will give the name, producer, location, and m of shipment of these materials.

Water—All water used in concrete shall be clean, free from oil, acids, lies, sea salts, vegetable matter, or ingredients that are injurious to con

Joint Filler—All joint fillers used shall comply with the requirements therefor in Article 103 for Grade M. A. Joint Fillers.

3. GENERAL.

The completed foundation shall have the width, thickness and su contour shown on plans.

A cubic yard of concrete shall contain not less than four and sixty hundredths (4.64) bags of cement.

The Engineer shall compare the calculated amount of cement rec according to these specifications, with the amount actually used, as mined by actual count of the number of bags of cement used per da the amount of cement used during any three (3) consecutive days is le more than five (5) per cent, or if the amount of cement used durin one day is less by more than ten (10) per cent of the amount hereinl required, the Contractor shall, at his own expense, remove all such co and replace the same with new concrete, constructed according to specifications.

The subgrade must comply with the requirements specified in Articl 68 and 73. In addition it must be kept constantly wet at least fifty (5 in front of the mixer. To secure the desired depth of saturation, th grade shall be sprinkled at frequent intervals. The rapidity with whi water shall be applied and the quantity used shall vary with the cha of the subgrade. The depth of saturation for sand and gravel sub shall not be less than four (4) inches, for clay and clay loam subgrad less than three (3) inches. The rate the water is applied and meth sprinkling employed, shall be such as not to form pools of water c surface of the subgrade yet all parts of the subgrade must be saturated depth required before any concrete is applied thereon.

After the subgrade has been properly wet it must be protected i manner ordered by the Engineer so that ruts are not formed durin hauling of the aggregate or paving mixtures.

All materials used in a concrete foundation must be kept clean transportation and hauling. Neither the coarse or fine aggregate sh deposited upon the subgrade shoulders or adjacent gutters unless perm is given therefor in the "Proposal." When deposited in piles adjac the work the ground upon which the material is deposited must be firm, well drained and free from all vegetable matter. All devices u measuring these aggregates shall be so constructed that they will ho exact volume of material required, and meet the approval of the Engin

No concrete shall be prepared or laid until the condition of the equip that will be used in the preparation thereof has been approved in writi the Engineer. This approval will be required for each contract and sh requested by the Contractor sufficiently in advance of starting work t mit of any required changes being made without delaying the work.

The Contractor shall provide such measuring devices as will insu required quantity of each ingredient being used in each batch. Al devices and the method of measuring the materials must be approved l Engineer. A bag of portland cement ninety-four (94) pounds net, sh considered as one (1) cubic foot.

The proportions of fine and coarse aggregate required to be used to the specified cement content, also the consistency required and the cn strength of the concrete thus prepared, shall be determined by the Eng These factors must be determined for each contract during the prepa of the initial concrete. No concrete shall be laid until they have been

mined. When so determined they shall only be changed when the red cement content is not being secured. The Construction Inspector notify the Engineer when the initial concrete will be prepared, said to be given at least five (5) days previous to its preparation, also ever the required cement content is not being secured.

ncrete shall not be mixed or laid when the atmospheric temperature in ade or the temperature of the aggregate is at or below 32 deg. F. When en permission is secured from the Engineer to construct pavement when emperature drops below 32 deg. F. at night, the concrete must be pro-l from freezing by one of the following methods. Any concrete that een frozen before it is five days old shall be replaced.

After the strips of canvas or burlap have been removed, the concrete be covered with a six (6) to eight (8) inch layer of straw or salt hay over a canvas cover shall be spread and firmly fastened in place. This shall be at least four (4) feet longer than the pavement is wide, laid the pavement with edges overlapping, and the edges of each layer fastened in place by straps or weights. Upon this canvas there is then l another layer of straw if the weather is fairly severe.

Board are placed across the center of the concrete at frequent intervals which a steam pipe is laid. The entire pavement is then covered with en trestles slightly longer than the pavement is wide and which are of ent height to leave an air space of not less than six (6) inches above the nent surface. These boards are then covered with canvas or strips red paper which must be firmly fastened in place. Steam is then l through the pipe until the weather has moderated or the pavement east five days old.

ring very severe weather this method of protection should always be and it may be found necessary in extreme cases to cover the canvas a layer of salt hay or straw.

RFACE FINISH.

finished surface of the concrete shall be uniform in appearance, free all loose or partly imbedded stone, lean or porous spots, depressions jections that are over three-eighths (3/8) inch above or below the speci-rface of the concrete as determined by a straight edge, not less than ten eet long laid parallel to the center line of the pavement. It must also the required grade and parallel to the finished surface at all points.

NSISTENCY.

consistency of the concrete shall be determined by the slump method. the slump has been determined for concrete containing a given aggre-no subsequent concrete prepared from these aggregates shall have any r slump. All concrete that has a greater slump shall be removed from adway before any initial set has developed. Said slump shall be deter-with a truncated cone twelve (12) inches high, eight (8) inches diam-t the base, and four (4) inches diameter at the top.

en the require consistency of the concrete has been established by the d defined above, the crushing strength of this concrete shall be deter-by six (6) inch cubes. These cubes, and all subsequent cubes taken sted, shall be moulded and cured in the field in the same manner, and when twenty-eight (28) days old. In determining the average crush-rength of this concrete, not less than three (3) nor more than five (5) shall be taken at irregular intervals from different batches of concrete. the average strength of this concrete has been thus determined, all uent concrete prepared from the same aggregates shall have a crushing th of not less than seventy-five (75) per cent of this average, and not than ten (10) per cent of the individual samples shall have a crushing th less than ninety (90) per cent of this average.

XING CONCRETE.

materials shall be mixed in a concrete mixer of the batch type, having city of not less than three (3) bags of cement per batch of concrete of omposition herein specified. Said mixer shall be equipped with an atic locking device that will prevent materials being discharged before ave been in the mixer the required length of time, a water tank contain-adjustable overflow with the necessary valves to prevent water g into the tank while the tank is discharging into the mixer, and a speed tor that will prevent the drum from revolving slower than twelve (12) er than twenty (20) revolutions per minute. Each batch must be in in the mixing drum at least one and one-quarter (1¼) minutes or as longer as may be necessary to insure a uniform and homogeneous con-hat has the required consistency. If the timing device should be out of

order, the concrete must be mixed not less than two and one-half minutes until such time as said device is repaired. The drum mu completely emptied before mixing successive batches. The concrete be mixed only in such quantity as will be required for immediate use. concrete that has developed initial set or has been mixed longer than t (30) minutes before being deposited in place, shall not be used.

The different ingredients used must be perfectly clean, kept free foreign materials during the operation of handling, mixing, and placing. Contractor must prevent any segregation of the coarse or fine particles aggregate taking place during hauling or the handling, or the incl therewith of any foreign material when these materials are loaded int measuring bins or mixer.

The Contractor shall notify the Engineer, in writing, at least three (3) in advance when he is ready to prepare the initial concrete.

7. Placing Concrete.

After mixing, the concrete shall be deposited at once in successive ba upon the subgrade to the required depth and for the entire width pavement. Immediately after being thus deposited, the piles or batc concrete shall be uniformly distributed over the subgrade so that the r ing surface is fairly uniform in character, and sufficiently above the gr the finished surface that, after being struck off the surface thereof will compressed below the grade specified therefor.

When concrete is to be placed adjacent to railroad tracks, or aroun structures as catch basins, manhole tops, or other objects that project th the pavement, no concrete shall be placed within eighteen (18) inches tracks or structures until they have been set to the required grad alignment.

8. Finishing Concrete.

The concrete shall be brought to the required grade and curvature use of a hand strike board. This board must be at least eighteen (18) longer than the pavement is wide. A hand template shall be used t solidate the concrete and produce the required finish. Both the strike and template shall have the same curvature as that specified for the cr the pavement.

After being properly placed the concrete shall be struck off and the surface thereof tamped until thoroughly consolidated and of a u consistency and density. Additional concrete shall be added to all low and porous spots, and retamped to the required grade and density. concrete should not be tamped to the required grade and solidity late thirty (30) minutes after placing, but must be properly struck o tamped before any initial set has developed.

9. Curing and Protecting.

After the concrete has been properly struck off, tamped and tested, i be covered at once with strips of burlap or canvas laid perpendicular center line of the pavement. The edge of each strip shall overla adjacent strips about one (1) inch. The different strips of burlap sl at least two (2) feet longer than the width of the pavement.

When properly placed this covering shall be sprinkled at once witl cient water to saturate it and kept wet until removed. As soon as th crete has hardened sufficiently to prevent pitting, these strips sh removed and the concrete protected by covering it immediately wi hay or straw. This covering shall be spread in a layer not less than inches thick, loose, and must be added in sufficient quantity to com cover the concrete. During the spreading, care must be exercised th surface of the concrete is not marred or injured. As soon as spread, i be wet at once and kept constantly saturated for at least ten (10) The pavement must be kept closed to traveling public, contractor, en and officials, for at least fourteen (14) days, and as much longer Engineer may order.

The water pipe, which supplies the water for the concrete must removed before the time required for the curing of the adjacent co This pipe line must be provided with tees and stop cocks at intervals over two hundred (200) feet and must be of sufficient size to permit proper sprinkling of the concrete and the operation of the concrete m the same time.

The Contractor shall erect and maintain suitable barricades to prot concrete from traffic, domestic animals, etc. Any part of the co damaged from traffic or any other cause occurring prior to its final a ance, shall be repaired or replaced by the Contractor at his own expen

ıner satisfactory to the Engineer. Before any surface pavement materials deposited on the foundation, the covering shall be removed and disposed s directed by the Engineer.

permission is given to lay concrete when the temperature may drop ·w thirty-two (32) degrees Fahrenheit before the concrete is five (5) s old, the concrete shall be protected in the manner specified above.

SIDE FORMS.

he thickness of the pavement foundation and its alignment shall be ·rmined by side forms. These shall be set to the established line and le of the pavement foundation with their upper faces at the grade blished for the adjacent edge. They must be equal in width to the kness of the pavement foundation at the edge, shall be firmly held in e by lock nuts, clamps, and steel pins, and supported at all joints or else-re as needed to prevent the forms from springing out of alignment. 'orms shall have square ends with clamping devices which will lock adjacent ; firmly together. The anchoring pins must be not less than twenty-four inches long, and of sufficient size to firmly hold the forms in place. No ., nuts or clamps shall project above the top of the form or be so placed o interfere with the free movement of the strike board or tamper. All ıs must be straight, free from warp, clean when used, and oiled if so ·red. Forms shall not be removed sooner than fifteen (15) hours after adjacent concrete has been placed.

JOINTS.

xpansion joints shall be constructed at the end of each day's work, or n work is suspended for over thirty (30) minutes, and at all other places gnated on plans.

xpansion joints shall be of either the poured or premoulded type. When type to be used is not designated on plans, the Contractor may construct er. The bitumen used to form the joints and the method of manufactur-premoulded joints must comply with the requirements given therefor in cle 103.

he forms used to cast a poured joint must be so designed and used that concrete will not be injured by its removal, the opening will have the ified dimensions, be perpendicular to the pavement surface and axis must pproved by the Engineer. They shall be so set that the top edge is at same elevation as the surface of the concrete and firmly held in place ron rods or pins driven into the subgrade.

he bitumen used for pour joints shall be Grade P. A. and shall be applied temperature between 300 and 400 deg. F. Sufficient bitumen shall be l to fill the joint flush full. The joint must be opened to full depth both faces clean and dry when the bitumen is applied.

remoulded joints shall be formed by inserting during construction, sheets ›ituminized felt or prepared semi-solid bitumen complying with the ıirements given therefor in Article 103. These sheets shall be inserted ›endicular to the axis of the pavement and its surface. They shall be ıl in length to the width of the foundation, have the same width as the kness specified for said foundation, and the top edges cut to the required ·ature before installation. When two sheets are used for one joint, the tting ends must be cut square and held firmly together during installa-, placing and finishing of the concrete. After side-forms are removed, ends of the joints shall be cleaned of all concrete to the full depth.

he device used to hold the joint filler in position until the adjacent con-e has been placed, shall be a metal plate equal in length to the width ıe foundation, have one edge cut to the crown specified for the surface of foundation, be of sufficient thicknesss, and so designed that it can easily ıstened and held in place without springing out of shape or alignment.

REINFORCEMENT.

he concrete shall be reinforced at all points shown on plans with the size type of metal designated, also at all places where trenches or other ıings are made in the subgrade for the installation of drains or structures shown on plans. When no method of reinforcing the concrete over ıings made in the subgrade is shown on plans, it shall be reinforced as ws:

ne-half (½) inch deformed bars shall be placed perpendicular to the ch, two (2) inches above the bottom of the concrete foundation, spaced ve (12) inches to centers and shall extend for a distance at least twelve inches beyond each edge of the opening. Payment will be made for all reinforcement installed, not shown on plans, at the contract unit price pound in place.

Series of 1917

IOWA STATE HIGHWAY COMMISSION

AMES, IOWA

Standard Specifications Fc Earth and Gravel Road Construction

Revised series of 1917 distributed by the State Highway Comm sion under Chapter I-A, Title VIII, Supplement to the Code 1913 as amended by Acts of the Thirty-Sixth General Assembly

Section Three

EARTH ROADS

1. **Alignment.**—The center of the finished roadway shall conform in ali ment to the center stakes. These stakes shall follow, as nearly as possi the center line of the right-of-way.

2. **Grade Lines.**—The grade line shown on the profiles shall denote crown of the finished roadway at its center line.

3. **Cross-section.**—Unless otherwise provided the cross-section to be u is the standard cross-section of the Highway Commission for the road sys on which the work is located.

NOTE.—The Commission will approve changes in the standard cross- tion to meet local conditions, on specific improvements, but a change proved for one road shall not be construed to apply to other roads. In e case the proposed change should be submitted to the district engineer will make a field examination to determine the feasibility of the char proposed.

4. **Grading.**—Under this head will be included all excavation and bankments required for the formation of the earth roadway, cutting ditches along or contiguous to the road, forming the approaches to all roads and farm entrances, changing of stream channels, and all other ex vations and embankments connected with or incident to the constructio the road. Grading will be estimated under the following heads, viz.:

Solid rock excavation.
Loose rock excavation.
Earth excavation.

Solid rock excavation will include all rock in masses which can not be moved without blasting, also all detached rock or boulders measuring less than one cubic yard each.

Loose rock excavation will include all slate or other rock which car quarried or removed without blasting, also all detached rock or boulc measuring not less than one-fourth nor more than one cubic yard each.

arth excavation will include all loose stones, boulders, and other material very description as found, which are not included in the above specifica- s as solid and loose rock.

. **Excavation.**—Excavation shall be made in all cases to the required nment and cross-section. Any roots, stumps, or other timber encoun- d in the excavation shall be removed and burned or otherwise disposed s directed by the engineer, but shall not be placed in the embankments. materials taken from excavations shall be deposited in the embankments ess otherwise specified or directed by the engineer. The cost of moving same when the average length of haul does not exceed five hundred (500) will be considered as included in the price per cubic yard for excavation.

. **Provision for Drainage.**—If it is necessary in the prosecution of the k to interrupt or obstruct the natural drainage of the surface, or the of artificial drains, the contractor shall provide for the same during the gress of the work in such a way that no damage shall result to either lic or private interests. He shall then be held liable for all damages ch may result from any neglect to provide for either natural or artificial nage which he may have interrupted.

. **Intercepting Ditch.**—In cuts along sidehills where there is a possbilitiy urface water causing damage by flowing down the side slope of the cut, tch shall be constructed to intercept the surface water and prevent it n flowing into the cut. The contractor will be paid for this work as an a.

. **Borrow Pits.**—When sufficient material for the embankments is not inable within the side ditches and excavations as staked out, the con- tor shall make up the deficiency from borrow pits laid out by the engineer. rowing must be done from regular shaped borrow pits in order to admit eady and accurate measurements, care being taken not to unnecessarily re or disfigure the land. The banks must be sloped, the pits so con- cted that surface water will drain out and the premises left in a condition sfactory to the engineer. The right-of-way for borrow pits will be fur- ed by the county.

. **Berms.**—Wherever it becomes necessary to make an excavation along side of the road as in the construction of borrow pits, ditches, etc., a n not less than four feet in width shall be left between the toe of slope he roadway embankment and the top of the excavation bank.

o. **Waste.**—When the amount of cut exceeds the amount of fill the excess erial shall be deposited as directed by the engineer. Such material shall erably be used in widening the adjacent fills so as to reduce the side es thereon.

1. **Embankments.**—Embankments shall be carried up in horizontal rs, each of which shall be carried out to its proper width in the cross- ion of the roadway. Sod obtained in the cuts may be deposited in the ankments provided it is so placed as to be not closer than twelve (12) es to the finished roadway or subgrade. Stones obtained from cuts l be so distributed in the embankments as to not form pockets or ties. All existing slopes and surfaces of embankment shall be plowed re additional fill is to be made, so that the new material will bond with old.

2. **Guard Rail.**—Where the height of an embankment is over six feet, stantial guard rails shall be constructed along the shoulders. Such guard will be paid for at the price bid per lineal foot of rail. Where the height he embankment is six feet or less, the side slopes shall be flattened to a e not steeper than three to one (3 : 1) unless otherwise shown on the plans.

3. **Sod in Blade Grader Work and Shallow Fills.**—In blade grader work in fills so shallow that the sod cannot be kept at least twelve (12″) inches w the finished roadway, such sod, after being cut loose with blade grade plows, shall be disked and harrowed until it is reduced to small pieces ch will not interfere with traffic. These small pieces of sod shall not be osited in the middle of the road but shall be deposited near the shoulders shall be covered with earth. The middle portion of the road shall be ned of earth free from sod. The disking and harrowing of sod is included he price bid for excavation.

4. **Side Ditches.**—The side ditches shall be excavated to the depth, nment, and cross-section shown on the drawings. Care shall be taken ecure a uniform grade on the ditches so that the water will readily drain , and to secure smooth, uniform slopes on the ditch banks in strict con- nance with the drawings.

15. **Clearing and Grubbing.**—The ground included in the highway m be cleared of trees, stumps, brush, weeds and grass to the full width of rig of-way, unless otherwise directed. All timber, stumps, brush, and ot vegetable matter must be burned unless otherwise directed by the engine Such material shall not be placed in the embankments.

Where embankments are to be more than two and one-half feet in heig it will be sufficient to cut all trees, stumps, and brush close to the grou Where embankments are to be less than two and one-half feet in heig and in all excavations, all stumps and large roots must be grubbed out a burned or removed.

Unless otherwise specified, clearing and grubbing will be paid for as ex work, as provided in Section Two, paragraph 22. Allowance will be m for all grubbing in excavations for the roadbed, all grubbing in borrow ordered and staked out by the engineer to supply material for the emba ments, and all grubbing in embankments less than two and one-half high, but will not be allowed for embankments over two and one-half high, or in borrow pits made by the contractor without having been ordered by the engineer.

16. **Hedge rows.**—Hedges, under these specifications, are rows of tree bushes, used for fence purposes or wind breaks, containing at least th bushes or trees per rod. For removing such hedges the contractor will paid the price bid per rod.

17. **Measurements.**—Grading shall be estimated and paid for by cubic yard at the prices specified in the tender. Measurements of grac quantities will, in all cases, be made from the cuts or pits from which material is taken, by cross-sectioning before and after excavation, and volumes determined by the average end area method.

18. **Haul and Overhaul.**—The average length of haul shall be determi by locating the center of gravity of the cut and the center of gravity of corresponding fill. If the center of gravity of the cut is more than hundred (500) feet from the center of gravity of the corresponding fill, o haul at the rate of one cent per cubic yard per 100 feet will be allowed the entire amount of material in the cut for the distance between the cen of gravity in excess of five hundred (500) feet.

NOTE.—Should the engineer desire to eliminate any payment for overh a stipulation to that effect may be inserted in the instructions to bidd as provided in Section Two, paragraph 25.

19. **Tile Sub-drains.**—Tile sub-drains shall be put in wherever shown the plans. The tile used shall meet the requirements of the standard sp fications for farm drain tile adopted in 1916 by the American Society Testing Materials. The tile shall be laid true to grade and alignn established by the engineer. For furnishing and laying tile drains, the tractor will be paid at the price bid for such work.

NOTE.—The first requirement of road construction is to get a well-drai roadbed. For this reason, county engineers are instructed to require drainage on all portions of the highways where there is any question reg ing the adequacy of the surface drainage or the stability of the soil.

If possible, the flow line of the tile shall be placed a minimum dept five feet below the elevation of the roadway shoulders. No tile less t six inches in diameter shall be specified.

Where the grade of the side ditch is less than one per cent., inlets to tile shall be provided at intervals of about five hundred feet. These in shall be constructed by filling the trench for a length of about three with coarse gravel, broken stone, or other suitable proous material. top of the porous material shall be raised about eight inches above the of the trench.

20. **Finishing Stakes.**—The engineer shall set suitable finishing stake guide the contractor in finishing the road.

NOTE.—One of the most common defects in earth road construction is failure to bring the earth shoulders up to the proper grade and alignm The shoulders are often left low and irregular, thus resulting in an unsig road having too much crown in the center. This defect can be obvia only by setting stakes, giving the grade and alignment of the shoulders. finishing, the contractor should use a templet to fit the crown of the r and in this case stakes need be set only along one shoulder or along the ce line. If no templet is used, finishing stakes should be set along each shou and on the center line.

inishing stakes on fills should be set above the established grade so as to w the proper amount of shrinkage. Under average conditions the fol-ing percentages of shrinkage should give satisfactory results.

Depth of Fill	Percentage of Shrinkage
Up to 5.0 feet	15%
5.0 feet to 12.0 feet	12%
12.0 feet to 18.0 feet	10%

1. **Finishing.**—If the road is not to be surfaced with gravel, the contractor ll, after having brought it substantially to grade, complete the work in h a manner that the finished road will be smooth and true to cross-section, de and alignment. No extra compensation will be allowed for finishing his work must be included in the price bid for excavation.

f the road is to be surfaced with gravel, the earthwork necessary for ning the sub-grade shall be executed in the manner specified for the class gravel surfacing to be used. The preparation of the sub-grade for the vel surfacing is not included in the price bid for earthwork.

2. **Installing Temporary Culverts.**—Temporary culverts will be construed nean corrugated culverts, boiler pipe culverts, concrete tile culverts, or iron culverts not over thirty-six inches in diameter, and placed without manent bulkheads. The county will furnish and deliver temporary cul-ts at the railroad station. The contractor will be required to haul, perly place, and fill over such culverts. For this he will be paid at the e bid per lineal foot.

Item 51. Sand-clay Surface Course[1]

1.1. **Description.**—This item shall consist of a wearing course composed of intimate mixture, either natural or artificial, of properly proportioned d and clay, and shall be constructed on the prepared subgrade in accord-e with these specifications and in conformity with the lines, grades, pacted thickness, number of component courses, and typical cross-section wn on the plans.

1.2. **Material.**—Natural sand clay shall consist of sand and clay, or top-, occurring properly proportioned, and obtained from pits designated the engineer. After the pit has been stripped, the engineer shall inspect approve the material before it is placed on the subgrade. All material d shall be free from weeds, vegetable, or other injurious matter, and all ies of more than 1″ in diameter shall be removed by the contractor at the

1.3. Sand for an artificial mixture or to supplement a natural mixture ll be sharp, clean, free from dirt or loam, and not too fine. It shall not be d until approved by the engineer.

1.4. Clay for an artificial mixture or to supplement a natural mixture ll show resistance to slaking and be satisfactory to the engineer, shall have d binding qualities, and shall not be used until approved by the engineer.

1.5. **Construction Methods.**—Where it is necessary to bring the sand clay on the subgrade separately, and mix them in place, a trench shall ormed in the subgrade with the grading machine to receive the bottom er, which may be either sand or clay. No trenching of the subgrade l be required where the subsoil is of sand or clay that is to be mixed with clay or sand, as the case may be.

1.6. *a.* **Clay on Sand Subgrade.**—The clay shall be spread over the prepared grade in such quantities and to such depth that when mixed with the d a compacted surfacing of the width and depth shown on the plans will obtained. After the clay has been spread the contractor shall plow up d from beneath and add sand from the sides, but only in such amount t the net proportion of sand and clay is about 2:1 or in sufficient quantity hat the clay will slightly more than fill the voids of the sand.

1.7. *b.* **Sand on Clay Subgrade.**—This process is exactly similar to that paragraph above, except that the subgrade shall be plowed to a depth 4″, after which it shall be harrowed until completely pulverized; the sand ll be spread over the subgrade in such quantities and to such a depth that, n mixed with clay, a compacted surfacing of the width and depth, shown the plans, will be obtained. The depth to which the sand should be

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spread will depend upon the amount of sand contained originally in t clay of the roadbed. As near as practicable, only enough clay shall plowed up from beneath just to fill the voids of the sand, and no surplus clay will be allowed. Where the subgrade material consists of clay whi in the opinion of the engineer, is not considered suitable for use in the surfa the sand layer shall be spread first, and of a depth more than is sufficient use in surfacing, and as directed by the engineer. The surplus sand sh remain under the completed surface to serve to improve the drainage of road. The proper proportion of suitable clay shall then be hauled and spre on the sand, as in case *c* following.

51 8. *c.* **Sand and Clay on a Different Subgrade Soil.**—Where it is nec sary to bring the sand and clay on the road separately, the trench should filled with the bottom layer of material (which may be either sand or cl to such a depth, and then have the top layer spread upon it to such a de that when mixed together the sand and clay will show a properly prop tioned and uniformly mixed compacted surfacing of the width and de shown on plans.

51.9. *d.* **Natural Sand Clay.**—The surfacing material shall be spread the prepared subgrade to such a depth that, when compacted, it will be the width and depth shown on the plans.

51.10. In all cases, only sufficient clay to fill the voids of the sand shall used, the clay serving as a binder for the sand. On sections of road that not exposed to the sun and wind, as in dense woods, deep cuts, or on boggy sections, a smaller percentage of clay will be required, in proport to the smaller percentage of voids in the sand. On heavy grades, especi when exposed to the sun and wind, a greater percentage of clay will required. It shall be the charge of the contractor that the required amo of material shall be delivered in each 100′ station and uniformly distribu throughout each station.

51.11. After the material has been spread as prescribed in the several c above, the material shall be thoroughly mixed with a disc harrow. operations of plowing and harrowing shall be repeated until the sand clay are mixed thoroughly and uniformly in the proper proportions. A the mixing is completed, the contractor shall shape the roadway with a r machine or road drag and permit traffic upon it. After the first soal rain, the contractor shall plow and harrow the surfacing material unt practically becomes mud, after which he shall shape the surface and keep i shape by repeated dragging until it has dried out and is thorou compacted.

51.12. When the typical cross-section requires that this item be construc in more than one course, the additional courses shall be constructed ir pendently on the previously completed course in accordance with cla *c* or *d* of these specifications, and maintained and finished as provided ab

51.13. **Method of Measurement.**—Work and accepted material ha from prescribed pits to the road shall be measured by the cubic yar material, loose measurement, as delivered on the road.

51.14. **Basis of Payment.**—The material will be furnished by the cou unless otherwise provided in special provisions. The work performe prescribed in this item and measured, as provided above, shall be paid at the contract unit price per cubic yard bid for Sand-clay Surface Cou which price shall be full compensation for loading all material, hauling over ¼ mile, delivering on the road and finishing, all labor, equipm tools, and incidentals necessary to complete the work, except rolling, sprinkling. Hauling material into each quarter mile beyond the first qua mile shall be paid for at the contract unit price per cubic yard bid for Mate Hauled Additional Quarter Mile.

Item 52. Shell Surface Course[1]

52.1. **Description.**—This item shall consist of a wearing course comp of shell, and shall be constructed on the prepared subgrade, or comple base course, in accordance with these specifications and in conformity the lines, grades, compacted thickness, number of component courses, typical cross-section shown on the plans.

52.2. **Material.**—The shell shall consist of sound particles of oyster, c or other shells equally acceptable to the engineer, and shall not con more than 15 % of mud, clay marl, or loam. No shells which will no broken up during construction to pieces not larger than 2″ shall be allo

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he material delivered, and all such oversize shell shall be removed at the tractor's expense.

2.3. **Construction Methods.**—The material shall be delivered, and spread hand on the prepared subgrade, or completed course, to such depth that n compacted the thickness shown on the plans will be secured and shaped onform to the typical cross-section. Side forms and either cubical blocks enter guide forms of proper size shall be used to fix the depth of the loose erial. It shall be the charge of the contractor that the required amount naterial shall be delivered in each 100′ station and uniformly distributed ughout each station.

2.4. The work shall be rolled and sprinkled or opened to traffic as directed. contractor, as often as directed, shall work and dress the surface so that cross-section shall continue uniform and true to line and grade, and il the surface is smooth, hard, free from ruts and undulations and well ded to the width shown on plans, and the work is accepted. When the ical cross-section requires that this item be constructed in more than one rse, each additional course shall be constructed independently after the vious one has been completed and accepted, all as prescribed above.

2.5. **Methods of Measurement.**—Work and accepted material hauled to road shall be measured by the cubic yard of material, loose measurement, lelivered on the road.

2.6. **Basis of Payment.**—When a unit price for Shell is requested and lered in the proposal, the material furnished as prescribed by this item l be paid for at the contract unit price so bid per cubic yard. The work ormed as prescribed by this item and measured as provided above shall paid for at the contract unit price bid per cubic yard for Shell Surface rse, which price shall be full compensation for loading all materials, ling not over ¼ mile, delivering on the road and finishing, all labor, ipment, tools, and incidentals necessary to complete the work, except ng, and sprinkling. Hauling material into each quarter mile beyond first quarter mile shall be paid for at the contract unit price bid per cubic d for Material Hauled Additional Quarter Mile.

Item 53. Caliche Surface Course[1]

3.1. **Description.**—This item shall consist of a wearing course composed of che, and shall be constructed on the prepared subgrade or completed course in accordance with these specifications, and in conformity with lines, grades, compacted thickness, number of component courses, and ical cross-section shown on the plans.

3.2. **Material.**—Caliche shall consist of a natural mixture of approxi-ely equal proportions of calcareous dust and quartz sand with or without presence of gravel or small stones, all of which, when tested, shall pass a screen. Oversize material shall be removed at the contractor's expense.

3.3. **Construction Methods.**—The material shall be delivered, and spread hand on the prepared subgrade to such depth that when compacted the kness shown on the plans will be secured, and shaped to conform to the ical cross-section. Side forms and either cubical blocks or center guide ns of proper size shall be used. It shall be the charge of the contractor t the required amount of material shall be delivered in each 100′ station uniformly distributed throughout each station.

3.4. If, in the opinion of the engineer, it be practicable to do so, the che shall be puddled with water before being finally shaped and compacted. s puddling may be done either in the pit before the material is hauled on road, or it may be done by sprinkling with water after the material has n spread upon the subgrade. In case puddling is done in the material the caliche shall at once be hauled onto the road, spread by means of s, rakes, or shovels, shaped, and rolled before it has dried out. In case dling is to be done after it has been spread upon the subgrade, the surface ll be thoroughly harrowed, plowed, or otherwise opened up during the cess of sprinkling, in order to insure the proper puddling of the caliche. er thoroughly puddled, to the satisfaction of the engineer, the surface ll be shaped to a uniform thickness and cross-section, and the succeeding rse of material shall be added and puddled in the same manner. Each ceeding course shall be placed and puddled as soon after the proceeding as practicable.

3.5. The work shall be rolled or opened to traffic as directed. The con-tor, as often as directed, shall work and dress the surface so that the

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cross-section shall continue uniform and true to line and grade, and ur the surface is smooth, hard, free from ruts and undulations and well bond to the width shown on plans, and the work is accepted.

53.6. Methods of Measurement.—Work and accepted material hauled the road shall be measured by the cubic yard, loose measurement, as delive on the road.

53.7. Basis of Payment.—When a unit price for Caliche is requested a tendered in the proposal, the material furnished as prescribed by this it shall be paid for at the contract unit price so bid per cubic yard. When su price is not so requested, right-of-way charges and royalties on the mater in the pit will be borne by the county. The work performed as prescrit for this item, measured as provided above, shall be paid for at the contr unit price bid per cubic yard for Caliche Surface Course, which price, sh be full compensation for loosening and loading all material at the pit, hauli not over ¼ mile, delivering on the road, puddling, and finishing, all lab equipment, tools, and incidentals necessary to complete the work, exce rolling, and sprinkling. Hauling material into each quarter mile beyond t first quarter mile shall be paid for at the contract unit price bid per cubic ya for Material Hauled Additional Quarter Mile.

Item 54. Disintegrated Limestone Surface Course[1]

54.1. Description.—Thes item shall consist of a wearing course compo of disintegrated limestone, and shall be constructed on the prepared subgra or completed base course in accordance with these specifications, and conformity with the lines, grades, compacted thickness, number of com nent courses, and typical cross-section shown on the plans.

54.2. Material.—The material shall consist of a good quality of disin grated limestone, reasonably free from soil and clay, and when loaded fr the material pit shall not contain more than 25 % of material which v pass a ¼″ mesh screen. The disintegrated limestone shall be such as c be loosened up in the pit by the use of plows or picks and without the use explosives. Material containing gravel or hard flint pebbles will be admitt although all hard stones over 1½″ in their largest dimension, which will n be broken up during construction, must be thrown out at the pit by contractor at his own expense.

54.3. Construction Methods.—The material shall be delivered, and spre by hand on the prepared subgrade, or completed course, to such depth tl when compacted the thickness shown on the plans will be secured a shaped to conform to the typical cross-section. Side forms and either cubi blocks or center guide forms of proper size shall be used to fix the depth the loose material. It shall be the charge of the contractor that the requi amount of material shall be delivered in each 100′ station and uniforn distributed throughout each station.

54.4. After the material has been spread and shaped, the surface shall thoroughly sprinkled with water and rolled as soon as it has sufficien dried off. The contractor, as often as directed, shall work and dress t surface so that the cross-section shall continue uniform and true to line a grade, and until the surface is smooth, hard, free from ruts and undulatio and well bonded to the width shown on plans, and the work is accept When the typical cross-section requires that this item be constructed more than one course, each additional course shall be constructed indepe ently after the previous one has been completed and accepted, all as prescrit above.

54.5. Method of Measurement.—Work and accepted material hauled the road shall be measured by the cubic yard of material, loose measureme as delivered on the road.

54.6. Basis of Payment.—When a unit price for Disintegrated Limestc is requested and tendered in the proposal, the material furnished as prescrit by this item shall be paid for at the contract unit price so bid per cubic ya when such price is not so requested, right-of-way charges and royalt on the material in the pit will be borne by the county. The work perform as prescribed for this item, measured as provided above, shall be paid for the contract unit price bid per cubic yard for Disintegrated Limestc Surface Course, which price shall be full compensation for loosening a loading all material at the pit, hauling not over ¼ mile, delivering on t road, puddling and finishing, all labor, equipment, tools, and incident

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ary to complete the work, except rolling, and sprinkling. Hauling ial into each quarter mile beyond the first quarter mile shall be paid the contract unit price bid per cubic yard for Material Hauled Additional Quarter Mile.

Item 55. Iron-ore Topsoil Surface Course[1]

. **Description.**—This item shall consist of a wearing course composed n-ore topsoil, and shall be constructed on the prepared subgrade in lance with these specifications and in conformity with the lines, grades, cted thickness, number of component courses, and typical cross-section on plans.

. **Material.**—Iron-ore topsoil shall consist of hematite, hydrated ite, or limonite ore as found at the surface but of a quality free from ble matter, which when loaded from the material pit shall not contain than 15 % of clay. The material shall be such as can be loosened the pit by the use of plows or picks and without the use of explosives. ial containing gravel or hard pieces of ore will be admitted, although ces over 1½″ in their largest dimensions, which will not be broken up construction, must be thrown out at the pit by the contractor at his xpense. The material shall have a cementing value of not less than l be so graded that 40 to 75 % is retained on a 10-mesh screen when by laboratory methods.

. **Construction Methods.**—The material shall be delivered and spread d on the prepared subgrade to such depth that when compacted the ess shown on the plans will be secured and shaped to conform to the l cross-section, and rolled if required. Side forms and either cubical or center guide forms of proper size shall be used to fix the depth of se material. It shall be the charge of the contractor that the required t of material shall be delivered in each 100′ station and uniformly uted throughout each station.

. After the material has been spread and shaped, the work shall be or opened to traffic as directed. If the material is of such a quality adheres to the wheels of the roller after sprinkling, the surface shall ded, the necessary material being measured as surfacing material. ontractor, as often as directed, shall work and dress the surface so e cross-section shall continue uniform and true to line and grade and he surface is smooth, hard, free from ruts and undulations and well l to the width shown on plans, and the work is accepted. When the l cross-section requires that this item be constructed in more than one , each additional course shall be constructed independently after the us one has been completed and accepted, all as prescribed above.

. **Method of Measurement.**—Work and accepted material hauled to d shall be measured by the cubic yard, loose measurement, as delivered road.

. **Basis of Payment.**—When a unit price for Iron-ore Topsoil is ted and tendered in the proposal, the material furnished as prescribed item shall be paid for at the contract unit price so bid per cubic yard. such price is not so requested, right-of-way charges and royalties on terial in the pit will be borne by the county. The work performed as bed for this item, measured as provided above, shall be paid for at the ct unit price bid per cubic yard for Iron-ore Topsoil Surface Course, price shall be full compensation for loosening and loading all material pit, hauling not over ¼ mile, delivering on the road, finishing, all equipment, tools, and incidentals necessary to complete the work, rolling, and sprinkling. Hauling material into each quarter mile l the first quarter mile shall be paid for at the contract unit price bid ic yard for Material Hauled Additional Quarter Mile.

Item 56. Pea-gravel Surface Course[1]

. **Description.**—This item shall consist of a wearing course composed or pea gravel, and shall be constructed on the prepared subgrade, or ted base course, in accordance with these specifications and in conformity with the lines, grades, compacted thickness, number of component s, and typical cross-section shown on the plans.

. **Material.**—The gravel shall consist of hard, durable particles of mixed with sand or clay or similar binding material and when tested oratory methods shall fulfil the following requirements:

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Passing the 1″ screen	95–100 %
Retained on ¼″ screen	10– 35 %
Retained on 10-mesh sieve	35– 70 %

Of the material passing the 10-mesh sieve, 25 to 40 shall pass the 200-n sieve. The cementing value of the material passing the 10-mesh sieve s not be less than 50.

56.3. Construction Methods.—The material shall be delivered in bottom wagons or approved trucks, and uniformly dumped on the subg or completed course, spread to such depth that, when compacted, thickness shown on the plans will be secured, harrowed if necessary, shaped to conform to the typical cross-section. Each day's hauling be spread the same day. When the width of the base course is more 12′, the material shall be dumped in two equal rows. The thickness o course as well as the material shall be strictly uniform. Side forms, either center forms or cubical blocks, shall be used to fix the depth of material. All areas and "nests" of segregated coarse or fine material be removed and replaced with well-graded material and compacted.

56.4. The work shall be rolled and sprinkled, or opened to traffi directed. Ruts shall be kept filled twice a day or more as directed. V irregularities, depressions, or weak spots develop during the process of sha and setting up, the affected areas shall be corrected immediately by sca ing, adding material as needed, reshaping, and compacting. This pr shall be continued, and the course maintained with grading machin other equipment as required, to the required line, grade, and typical c section until the surface is smooth and hard, free from ruts and undulat well bonded to the width shown on plans, and the work is accepted.

56.5. When the typical cross-section requires that this item be constr in more than one course, each course shall be constructed independ after the previous one is completed and accepted. All as prescribed a

56.6. Method of Measurement.—Work and accepted material sh measured by the cubic yard of material, loose measurement, as deli on the road.

56.7. Basis of Payment.—When a unit price for Pea Gravel is requ and tendered in the proposal, the material furnished as prescribed fo item shall be paid for at the contract unit price so bid, which price include all pit charges, screening, and freight f. o. b. delivery points. such price is not requested the material will be furnished by the count of royalty and right-of-way charges, and the contractor will be pa Screening, as ordered, at the prices bid per cubic yard for Screening.

56.8. The work performed as prescribed for this item, measur provided under Measurement, shall be paid for at the contract unit bid per cubic yard for Pea-gravel Surface Course, which price shall b compensation for loading all material, hauling not over ¼ mile, deli on the road, spreading and finishing, all labor, equipment, tools, and dentals necessary to complete the work, except screening, rolling sprinkling. Hauling into each quarter mile beyond the first quarte shall be paid for at the contract unit price bid per cubic yard for Ma Hauled Additional Quarter Mile.

Item 57. Standard Gravel Surface Course[1]

57.1. Description.—This item shall consist of a wearing course com of gravel, and shall be constructed on the prepared subgrade, or com base course, in accordance with these specifications and in conformity the lines, grades, compacted thickness, number of component course typical cross-section shown on the plans.

57.2. Materials.—The gravel shall consist of hard, durable partic stone mixed with sand or clay or similar binding material, and when by laboratory methods shall fulfil the following requirements:

Passing 1″ screen	95–100%
Retained on ¼″ screen	50– 75%

Of the material retained on the ¼″ screen, 35 to 75 % shall be re on the ¾″ screen.

57.3. The material passing the ¼″ screen shall be known as "bi and of this material 15 to 35 % shall pass the 200-mesh sieve. The cem value of the binder shall be not less than 50.

[1] Texas.

. The gravel may be crushed, and may be bank run, or the binder be added and incorporated by approved methods as hereinafter ed.

. **Construction Methods.**—The material shall be delivered in slat- n wagons or approved trucks and uniformly dumped on the subgrade mpleted course, spread to such depth that, when compacted, the ess shown on the plans will be secured, harrowed if necessary, and d to conform to the typical cross-section. Each day's hauling shall be l the same day. When the width of the course is more than 12′ the ial shall be dumped in two equal rows. The thickness of the course ll as the material shall be strictly uniform. Side forms, and either forms or cubical blocks, shall be used to fix the depth of loose ial. All areas and "nests" of segregated coarse or fine material be removed and replaced with well-graded material and compacted.

. If the gravel is deficient in binder as prescribed under Materials , after it is spread and shaped, additional binder shall be furnished and d in the amount directed by the engineer so as to comply with the g requirements. Such binder shall be measured and paid for as pro- for the normal gravel, and shall be carefully and evenly incorporated he material in place as directed by the engineer.

. The work shall be rolled and sprinkled, or opened to traffic as ed. Ruts shall be kept filled twice a day or more as directed. When arities, depressions, or weak spots develop during the process of g and setting up, the affected areas shall be corrected immediately by ing, adding material as needed, reshaping, and compacting. This s shall be continued, and the course maintained with grading machines ner equipment as required, to the required line, grade, and typical section until the surface is smooth and hard, free from ruts and undula- well bonded to the width shown on plans, and the work is accepted.

. When the typical cross-section requires that this item be constructed re than one course, each course shall be constructed independently he previous one is completed and accepted, all as prescribed above.

. **Method of Measurement.**—Work and accepted material shall be red by the cubic yard of material loose measurement, as delivered on ad.

o. **Basis of Payment.**—When a unit price for Gravel for Surface e is requested and tendered in the proposal, the materials furnished as ibed for this item shall be paid for at the contract unit price so bid, price shall include all pit charges, crushing, screening, and freight . delivery points. When such price is not requested the material will nished by the county free of royalty and right-of-way charges, and the ctor will be paid for all Crushing and Screening or Screening, as d, at the prices bid per cubic yard for Crushing and Screening or for ing.

1. The work performed as prescribed for this item, measured as led under Measurement, shall be paid for at the contract unit price bid ubic yard for Standard Gravel Surface Course, which price shall be mpensation for loading all material, hauling not over ¼ mile, deliver- the road, spreading and finishing, all labor, equipment, tools, and ntals necessary to complete the work, except crushing, screening, , and sprinkling. Hauling into each quarter mile beyond the first r mile shall be paid for at the contract unit price bid per cubic yard aterial Hauled Additional Quarter Mile.

COURSE (NEW YORK STATE SPECIFICATIONS, ITEMS 47 to 55)

Item 47—Top Course—Water Bound Macadam—Gravel

. Under this item the Contractor shall furnish and place upon the n course, gravel of an approved character to form the top course.

. The top course shall consist of approved gravel of the character before specified and of the thickness shown on the plans, together he binder necessary to properly fill and bind the course. For this e gravel of No. 3 size with, when approved by the Engineer, a certain t of No. 2 size, may be used. (See page 720 for meaning of these numbers ize.) Run of bank gravel shall not be used except by written permis- the Division Engineer; this permit must be given in advance, shall the locality from which it is to be taken, and contain a proviso that material should at any time become unsatisfactory its use shall at once

cease and proper material be furnished without additional recompense if it has to be imported. A copy of any such permit must be filed wit State Highway Commission, and on this permit must be the writter signed acceptance of all the conditions by the Contractor.

47.3. The gravel shall be spread evenly upon the bottom course, cubical blocks for gauging, to such a depth as to insure the required ness after it shall have been thoroughly rolled and compacted wit approved roller weighing 10 to 12 tons. Care shall be exercised to pr any depressions or surface irregularities after rolling the gravel and bir

47.4. When the gravel consists of screened material the binder consist of a mixture of the sand screened out and the No. 1 size, with er clay added when necessary to make a percentage of 12 to 17, but r exceed 17 per cent. The binder shall be added as directed by the Enginee thoroughly swept into interstices thereof until they are filled. After sp ling the surface it shall be thoroughly rolled. The adding of binder necessary and the sweeping, sprinkling and rolling shall continue unt course is compacted. The pavement shall then be opened to traffi shall be in a first-class and satisfactory condition at the time of its accep

47.5. When the gravel consists of run of the bank the binder sh the fine particles contained in the material in its natural state excep when so ordered in writing by the division Engineer a small perce of clay or loam may be added, when necessary to properly bind the c

The particles shall be of such size as will pass through a 3½-inch ci hole, and shall be well graded. Gravel shall be of such nature tha material passing a ¼-inch screen shall not be more than five per centun feasible, see page 138) in excess of the voids in the remaining material its separation therefrom. Should at any time during the work and fc reason the gravel fail to maintain suitable proportions of the coarse an particles, the Contractor shall by the addition of selected material and factory manipulation produce a top course meeting the above requirem

Care shall be taken to keep the large stone away from the surface.

After sprinkling the surface it shall be thoroughly rolled. Addi material forbinder shall be added where necessary and the sprinklin rolling shall continue until the course is compacted. The pavement then be opened to traffic and shall be in a first-class and satisfactory dition at the time of its acceptance.

47.6. The quantity to be paid for under this item shall be the m of cubic yards of compacted material in place in the completed c The amount will be computed by multiplying the finished cross-s of the top course as shown on the plans or ordered by the Enginee the length of the top course measured along the axis of the pavement.

The price bid under this item shall include the furnishing, placing, r filling, and puddling of the material, and all labor, material and inci expenses necessary to complete the work.

Gravel or screenings remaining loose on the surface after the w completed shall not be estimated as a part of the depth of the top c but payment therefor shall be included in the price bid for this item.

Item 48—Top Course—Water Bound Macadam—Broken Stone

48.1. Under this item the Contractor shall furnish and place upo bottom course broken stone to form the top course.

48.2. The top course shall, except as noted below, consist of No. 3 b stone as shown on the plans and of the thickness shown thereon, to with the binder necessary to properly fill and bind the course. The l shall consist of screenings and No. 1 stone mixed.

48.3. The No. 3 stone shall be spread evenly upon the bottom c using cubical blocks for gauging, to such a depth as to insure the rec thickness after it shall have been thoroughly rolled and compacted. shall be used in the spreading of the stone that no irregularities in the co shall develop in the rolling; every such irregularity that does occu Contractor shall remove before adding the smaller material. The r shall be done with a 10 to 12 ton self-propelled roller of approved pa and shall be continued until the layer of stone does not creep or wave of the roller.

After the stone has been compacted to the satisfaction of the Eng a light coating of binder shall be spread on dry by shoveling from

ously placed alongside the pavement, and immediately swept in and ughly rolled. Care must be taken throughout to add the binder only ht coatings and to thoroughly sweep each coating in order that the num amount of binder may be worked in to fill the voids. The spread-nd sweeping and rolling shall be continued until no more binder will dry, after which the macadam shall be sprinkled until saturated, the kler being followed by the roller. If the sub-grade should become o such an extent that the pavement becomes unstable and waves the roller, the roller shall be taken off and this portion left to dry out puddling is resumed.

re screenings shall be added where necessary, and the sweeping, dling, and rolling shall continue until a grout has been formed that ill all the voids and be pushed into a wave by the wheels of the roller. the wave of grout has been produced over the whole section of the dam this portion shall be left to dry out, after which it shall be opened ffic. The macadam shall be repuddled and back-rolled on succeeding as much as may be necessary to secure satisfactory results. The dam shall then be covered with a wearing carpet of screenings at least eighths of an inch thick; this wearing carpet shall be maintained and ed until the whole road is accepted. During all the working hours the roller is not needed for rolling the fills, sub-grade, shoulders nfinished courses of the pavement, it shall be employed in back-rolling rlier portions of the macadam.

4. The quantity to be paid for under this time shall be the number bic yards of compacted material in place in the completed course. mount to be estimated shall be computed by multiplying the finished section of the top course as shown on the plans or ordered by the eer, by the length of the top course measured along the axis of the nent.

price bid shall include the furnishing, placing, rolling, filling and ing of the material, and all labor, material and incidental expenses, sary to complete the work.

1 stone or gravel, chips or screenings remaining loose on the surface the work is completed shall not be estimated as a part of the depth of p course, but payment therefor shall be included in the price bid for em.

Item 49—Cleaning Old Pavement

1. The purpose of the work called for under this item is to prepare d macadam or old concrete surface for the application of a new top or a wearing carpet.

2. Under this item the Contractor shall clean the old macadam or ete surface by the use of seal hand brooms or by the use of mechanical ers of approved type, as directed by the Engineer, so as to completely er but not dislodge the embedded stones of the pavement.

mud, dust, and other dirt so swept off shall then be removed and ited in such places and in such manner as the Engineer may direct.

3. Ruts and depressions of a greater depth than one inch below the al surface of the pavement shall be completely swept out by hand ns until all loose material has been removed and the embedded stones lly uncovered.

s operation of cleaning out the ruts and depressions and filling them thoroughly compacted stone and binder to the general level of the e, shall precede the general operation of cleaning the macadam surface.

4. The amount to be paid for under this item shall be the actual er of square yards of old macadam or concrete, including ruts and ssions, cleaned in accordance with the above sections and to the ction of the Engineer.

price bid shall include all labor, tools, appliances, the removal of mate-eaned from the surface, and all other expenses incidental thereto.

Item 50—Scarifying and Reshaping Old Macadam

1. The purpose of the work under this item is to prepare old macadam nent for the application of a top course.

50.2. Under this item the Contractor shall thoroughly scarify the macadam by hand picking or by means of a mechanical scarifier of appro type. Unless specifically authorized by the Engineer, the use of a ro with spiked wheels will not be permitted.

The loosened stones shall then be forked or raked over as directed the Engineer, after which the macadam shall be compacted by roll with a self-propelled roller weighing not less than 10 tons until an e and firm surface is produced. If necessary in order to satisfactorily co pact the stones, the macadam shall be sprinkled during the process rolling.

50.3. The quantity to be paid for under this item shall be the act number of square yards, scarified, reshaped, rolled and compacted to satisfaction of the Engineer, and the price stipulated shall include all la appliances and expenses incidental thereto.

Item 51—Surface Treatments with Bituminous Material

51.1. Under this item the Contractor shall apply bituminous mate and shall apply broken stone or gravel of specified sizes as a wearing ca to a new or old pavement of macadam, concrete, or any other substanc type, as shown on the plans or ordered by the Engineer.

51.2. If the pavement to be treated is a newly built macadam or concr after it shall have become thoroughly dried and hardened, it shall be sw clean of all dust, dirt or other loose material; if ordered by the Engir the sweeping of the macadam shall be continued until the voids are exp in the surface to a satisfactory depth, not exceeding one-half inch. The p bid, under this item, shall include the aforesaid cleaning of the pavemer

If the pavement to be treated is an old macadam or old concrete, cleaning shall be paid for under item "Cleaning Old Pavement."

51.3. After the pavement shall have been cleaned to the satisfac of the Engineer, and when dry, the bituminous material shall be unifor sprayed over the surface by means of an approved pressure distribu The bituminous material for hot application shall be heated to a perature between 250 degrees and 350 degrees F. as required, and w tar is used, it shall be heated to a temperature between 200 degrees 250 degrees F. as required.

The amount of bituminous material to be used in any one applica shall not be less than one-sixth nor more than one-half gallon per sq yard, the precise quantity depending upon the character of the paven the materials and the local conditions. The Contractor shall, there be subject entirely to the direction of the Engineer in this respect.

51.4. The bituminous material applied as above specified shall be immediately covered, while soft, with a uniform layer of approved br stone of No. 2 or No. 1 size, after which the stone shall be rolled with a propelled roller of approved weight. If ordered by the Engineer anc application of bituminous material shall then be made to be followed b application of approved No. 2 stone or approved No. 1 stone, and a rolled to the satisfaction of the Engineer.

The quantity of No. 2 stone and of No. 1 stone to be used shall be ficient to completely cover the bituminous material and shall be sprea two or more thin applications, the roller being used after each spread The total amount of stone to be used after each application of the bitumi material being that which will become imbedded under the pressure of roller. The final application of the stone shall be of No. 1 size.

51.5. Gravel, which has been tested and approved for use, may be stituted for broken stone if screened to produce particles correspon with No. 2 and No. 1 sizes.

51.6. No bituminous material for surface treatment shall be pl between October 15th and May 15th, except by written permissio the Engineer, nor when the air temperature on the work is below 50 degree nor when the pavement is damp or in an otherwise unsatisfactory condi

51.7. Under this item the Contractor shall be paid for the numbe gallons of bituminous material furnished in and incorporated in the in accordance with these specifications and the orders of the Engi Bituminous material, that has been wasted or that has been rend unfit for use by over-heating or by long-continued heating, shall no paid for. For purposes of measurement, a gallon shall be a volum

ubic inches and measurement shall be based on the volume of the inous material at a temperature of 60 degrees F.

price bid shall include the furnishing, hauling, heating and applying tuminous material, and shall also include the spreading, rolling and oration of the stone into the wearing carpet.

s item shall not include the furnishing of the No. 1 and No. 2 stone vel, nor the delivery of same along the side of the road; these will be for under Items Screened Gravel or Broken Stone Loose Measure, tively.

em 52—Top Course Bituminous Macadam—Penetration Method

. Under this item the Contractor shall furnish and lay a broken top course composed of fragments of the specified sizes, and incor- therewith bituminous material introduced from the surface by means approved pressure distributor.[1]

and spreading from pots or hods is more satisfactory for the first coat ot for the flush coat.

. After the bottom course shall have been completed to the satis- n of the Engineer, a course of approved No. 3 broken stone shall be spread thereon in such quantity that after the application of the inous material and broken stone of smaller sizes, hereafter specified, ial compacted thickness of the top course shall be as called for on the or ordered by the Engineer.

No. 3 stone shall then be smoothed out by passing over it a few a self-propelled roller weighing approximately 10 tons, after which inous material of the kind specified in the proposal, heated to a tem- ure between 250 degrees and 350 degrees Fahrenheit if asphalt is and between 200 degrees and 250 degrees if tar is used, shall be evenly ling over the surface. The quantity of bituminous material to be n the first application shall be the amount ordered by the Engineer, will approximate $1\frac{3}{4}$ gallons per square yard for a top course 3 thick, with a proportional reduction in the quantity for thinner courses. surface shall then be immediately covered with a layer of approved broken stone, after which it shall be compacted with a self-propelled weighing approximately 10 tons; during the rolling process, additional broken stone shall be applied and broomed about until the voids in o. 3 stone are entirely filled.* The rolling shall be continued until the of stone is thoroughly compacted and its surface is true and even to stablished grade and conforms in all respects to the requirements ed for finishing and testing the surface of "Top Course Bituminous dam, Mixing Method—Type 1."

. After this portion of the work shall have been completed to the ction of the Engineer, all loose stone shall be swept from the surface sealing coat of one-half gallon of bituminous material per square hall be applied by means of an approved pressure distributor. After shall be immediately covered with approved No. 1 broken stone, and broomed about by experienced workmen, and again rolled; the shall be continued and additional No. 1 stone shall be applied until a h, uniform surface is produced.

. Before being opened to traffic a layer of No. 1 broken stone approxi- y one-half inch thick shall be spread loose on the surface for wearing .

. The quantity to be paid for under this item shall be the number bic yards of compacted material in place in the completed course. mount to be estimated shall be computed by multiplying the finished section of the top course, as shown upon the plans or ordered by the eer, by the length of the top course measured along the axis of the ent.

price bid shall include the heating and placing of the bituminous ial, the furnishing, placing, rolling and filling of the broken stone, ll labor, materials, and incidental expenses necessary to complete the urse.

s item shall not include the furnishing and delivery of the bituminous

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*oo much rolling is injurious while the oil is hot; better results are ned by waiting till the next day to compact; the course should be rolled in the morning for 10 days and gradually hardened down.

material; such furnishing and delivering will be paid for under the covering such material.

No. 1 broken stone or gravel, chips or screenings remaining loose the surface afer the work is completed shall not be estimated as a pa the depth of the top course, but payment for these shall be included ir price bid for item 52.

Item[1] 47. Top Course. Bituminous Macadam, Penetration Metho

a. **Work.**—Under this item the contractor shall furnish and lay a br stone or broken-slag top course composed of fragments of the specified s and incorporate therewith bituminous material applied by means pressure distributor of an approved type. The laying of this course wil be allowed after Oct. 15 except under the written permission of the engi and the approval of the Deputy Commissioner.

b. **Method.**—After the bottom course shall have been completed tc satisfaction of the engineer, a course of clean approved No. 3 broken s or broken slag shall be evenly spread thereon in such quantity that be the application of the bituminous material and broken stone or broken of small sizes, hereafter specified, the compacted thickness of the top cc shall be as called for on the plans.

No stone with dust coating will be permitted for use in this course. any stone spread for this course becomes wet or dirty, it must be allowe dry to the full depth of the course, and dirty stones removed and repl with clean stone before the pouring of bituminous material proceeds.

All filler for the top course shall be delivered and piled alongside the before the top course is placed.

The No. 3 stone or slag shall then be compacted by passing over it a propelled roller weighing approximately 10 tons, afetr which bitumi material of the kind specified in the proposal (heated to a tempera between 200 and 300°F. when tar is used and between 250 and 325°F. asphalt is used) shall be evenly spread over the surface by the use c approved pressure distributor, operating under a pressure of 50 lb. square inch or more as the engineer may direct. The quantity of bitumi material to be used in the first application shall be the amount ordere the engineer, which will approximate 2 gal. per square yard for a compa top course 3″ thick, with a proportional reduction in the quantity thinner courses.

In order to insure uniformity at the junction point of two applicatio will be required that the distributor should in starting lap back or previous application, covering the lap with building paper, to avoid eith excess or an insufficient quantity at the junction point. The paper then be removed and destroyed.

The surface shall then be immediately filled with clean No. 1 broken or broken slag, after which it shall be compacted with a self-prop roller weighing approximately 10 tons; during the rolling process, addit broken stone as specified above or broken slag shall be applied and broo about until the voids in the No. 3 stone or slag are entirely filled. The rc shall be continued until the course of stone or slag is thoroughly compa and its surface is true and even to the established grade.

c. **Testing Surface.**—Before placing the sealing coat, the pavement be tested with a 10′ straight-edge laid parallel with the center line o pavement, and any depressions exceeding ½″ shall be satisfactorily e nated or the pavement relaid.

d. **Sealing Coat.**—After this portion of the work shall have been pleted to the satisfaction of the engineer, all loose stone or slag shall be s from the surface and a sealing coat of approximately ¾ gal. of bitumi material per square yard shall be applied by means of an approved pre distributor. After this it shall be immediately covered with approved 1 broken stone or slag, spread and broomed about by experienced work and again rolled; the rolling shall be continued and additional No. 1 s or slag shall be applied until a smooth, uniform surface is produced.

e. **Wearing Carpet.**—Before being opened to traffic a layer of No. 1 br stone or slag approximately ¼″ thick shall be spread loose on the su for wearing course. After the road has been open to traffic for 10 day as the engineer may direct, this wearing carpet shall be again sprea sweeping the surplus from the sides to the center of the pavement.

f. **Measurement and Payment.**—The quantity to be paid for under item shall be the number of cubic yards of compacted No. 3 stone or

[1] New York.

ich shall be computed by multiplying the finished cross-section of the top ırse, as shown upon the plans or ordered by the engineer, by the length of : top course measured along the axis of pavement, making no deduction for ch basins and manholes.

`he price bid shall cover the heating and placing of the bituminous terial, the furnishing, placing, rolling, and filling of the broken stone or ›ken slag, and all labor, materials, and incidental expenses necessary to nplcte the top course.

This item shall not cover the furnishing and delivery of the bituminous terial; such furnishing and delivering will be paid for under the item cover- such material.

Vo. 1 broken stone or slag shall not be estimated as a part of the depth of top course, but payment for same shall be included in the price bid for s item.

SURFACE TYPE FA-BC-2

75J. FINE AGGREGATE. BITUMINOUS CONCRETE

Two Course

DEFINITION.

ι bituminous concrete pavement is defined as one which is composed of ın stone, bituminous sand and a mineral filler, bound together with ıminous cement.

THICKNESS AND WEIGHT.

`his pavement shall be laid in two courses—the top or wearing course and bottom or binder course. The top course must have an average thick- s, after ultimate compression, of not less than one and one-half (1½) ıes, shall not be less than one and one-quarter (1¼) inches nor more than (2) inches thick at any point, and have an average weight of not less than hundred eighty-five (185) pounds per square yard, exclusive of the eegee coat. The bottom course shall have an average thickness, after mate compression, of not less than one and one-half (1½) inches and ll not be less than one and one-quarter (1¼) inches nor more than two l one-half (2½) inches thick at any point, and have an average weight of less than one hundred seventy (170) pounds per square yard of surface.

MATERIALS REQUIRED.

`he binder course shall be prepared from ¾-in. trap rock, dolomite or..... ıminous sand, mineral filler, and asphaltic cement Grades NA², LM², I² or..........

`he surface course shall be prepared from dustless screenings made from p rock, dolomite or............, bituminous sand, mineral filler and haltic cement Grades NA², LM², CM², or............

`hese materials shall comply with the requirements given therefor in icles 92, 95-A and 99.

COMPOSITION.

`he finished pavement, exclusive of any bituminous sealing mixture lied, shall not vary in composition more than the limits given below:

Screens and sieves		Type of openings	Bottom course		Top course	
Passing	Retained on		Minimum, %	Maximum, %	Minimum, %	Maximum, %
1½-in.	1-in.	Circular	0.0	25.0		
1-in.	½-in	Circular	40.0	70.0	0.0	15.0
½-in.	½-in.	Circular	5.0	20.0	20.0	45.0
½-in.	10-mesh	Square	0.0	15.0	10.0	25.0
10-mesh	30-mesh	Square	3.0	10.0	6.0	18.0
30-mesh	50-mesh	Square	4.0	8.0	6.0	12.0
50-mesh	80-mesh	Square	4.0	8.0	6.0	12.0
80-mesh	200-mesh	Square	3.0	12.0	5.0	11.0
200-mesh	....	Square	2.0	8.0	5.0	8.0
al stone content ret. on 10-mesh....			75.0	90.0	50.0	70.0
umen content			4.0	5.5	6.0	8.0

5. Estimating Ingredients.

The proportions of the different ingredients required to prepare the p ment shall be determined by weight. The pavement must not vary in c position more than the specified limits given.

The bitumen content is based upon the finished pavement, exclusiv any mineral or bituminous surface coating applied. The exact amour mineral filler and asphaltic cement to use between the limits defined he shall be determined by the Testing Engineer. In calculating the percent of the various sizes of ingredients of which the mineral aggregate is compc the bitumen is included. The actual amount of paving mixture used s be estimated from the railroad shipping weights of the ingredients u batches of paving mixtures prepared and used, or loads delivered and

6. Preparation.

The quantity of ingredients used per batch in the preparation of both top and bottom courses must be accurately determined by either weigh measurement, depending upon the type of plant and kind of material b used. In either case the devices used in measuring these ingredients r be standardized whenever so requested, also the manner in which these de are used shall be demonstrated and the quantity of material thus sec verified, whenever so ordered by the Inspector or Engineer. The plant in preparing the paving mixtures shall comply with the requirements g below.

The mineral filler should be so cast into the mixing chamber that evenly distributed over the surface of the aggregate and not dumped in end of the mixing chamber. The asphaltic cement should also be a slowly in a thin sheet the full width of the mixing chamber. If the and asphaltic cement are not added in this manner, the time require produce a uniform paving mixture will be two (2) or more minutes per ba otherwise, from one (1) to one and one-half ($1\frac{1}{2}$) minutes will be suffic

(*a*) Wearing Surface. The aggregate for the wearing surface must ha temperature of not less than 275°F. nor more than 350°F. when ready t coated with the asphaltic cement. The asphaltic cement, when applie the aggregate, must have a temperature of not less than 250°F. and not than 350°F., and must be free from unmelted lumps. The mineral may be added cold and must be thoroughly dry.

In the preparation of this mixture the aggregate is first added to the ing chamber, then the mineral filler. After the mineral filler has be uniformly distributed through the aggregate the asphaltic cement is a and the mixing continued until a bituminous mixture is secured that is form and homogeneous in composition and all the particles of the aggre are uniformly and completely coated with the hot asphaltic cement.

(*b*) Binder Course. The aggregate for the binder course must have a perature of not less than 250°F. nor more than 350°F. when ready t coated with the asphaltic cement. The asphaltic cement shall have same temperature when applied as specified for the wearing surface. mineral filler is required in the binder.

In preparing the binder course, the stone and sand are run into the m chamber and the asphaltic cement added as soon as the sand is thorou incorporated with the stone. The mixing is continued until all part of the aggregate are completely coated with hot asphaltic cement and mixture is uniform and homogeneous in composition. Care must be cised in the preparation of this binder that the aggregate does not get too that excess fine material or asphaltic cement are not used if rich spo the binder are to be avoided.

7. Hauling and Handling.

The paving mixtures must be kept clean during hauling and handling covered during transit with canvas or other materials which will retain temperature. These mixtures must not be hauled such a distance that s gation of the ingredients takes place or that a crust is formed on the sur bottom or sides of said mixture which has a temperature lower than required. These mixtures must not be dumped any faster than they be properly handled by the shovelers nor at such a rate that over si tons of paving mixture are upon the platforms at the same time. must be spread immediately after being dumped and must be kept perf clean until spread. Any part of the paving mixture which becomes or chilled below the required temperature must be rejected. All pa mixture must be carefully removed from the spot upon which it was pl before any additional paving mixture is placed thereon.

'he mixture for the wearing surface, when dumped on the platforms, must e a temperature between 272°F. and 350°F.; for the binder course, ween 250°F. and 325°F. Any portions of the wearing surface mixture t become chilled below 250°F. or of the binder below 225°F. before being ead shall be discarded.

'hese paving mixtures may be dumped direct on a concrete foundation, when the foundation is macadam or telford they shall be dumped on al or wooden platforms which must be of such size that the paving mix- e will not fall off when dumped thereon or work off during spreading. e wearing surface mixture may be dumped on the binder. However, h load of paving mixture must be dumped outside of the area over which vill be spread.

ll vehicles used in transporting paving mixtures must have tight-fitting toms which will hold hot, thin mixtures without leaking. When motor cks are used the bodies should be insulated for long hauls during cold ther so that the paving mixtures adjacent the ends and sides will not ome chilled during transit. All motor trucks used for this purpose must e dump bodies that will permit the rapid unloading of these mixtures. e inside surface of these bodies should be oiled just before loading. How- r, only sufficient of this oil shall be used to coat the surface. No pools oil must appear on the bottom of the truck.

SPREADING AND RAKING.

mmediately after the paving mixture has been dumped upon the plat- m, it shall be deposited at once upon the foundation or binder with hot vels in such a manner that any segregation of the ingredients or irregulari- in composition will be eliminated as much as possible. After being thus osited it shall be so spread with hot iron rakes that after being thoroughly apacted by tamping and rolling each course shall have the average thick- s, surface finish and contour specified.

)uring spreading and raking the workmen must not walk over or stand on paving mixture except when necessary to correct irregularities in the ini- raking. The paving mixture shall not be spread any faster than it can properly handled by the rakers.

a) Binder. The binder course shall only be rolled sufficient to properly npact and bind together the ingredients of the aggregate; also to disclose open spots or low places. When any depressions are discovered they ll be filled with additional binder and rerolled so that the surface of this der course shall be of a uniform character, at the required grade and have specified crown.

The surface of the binder course after compression shall not show in any ce an excess of asphaltic cement or fine matrix, and any area of one square t or more showing an excess of asphaltic cement shall be cut out and laced with proper binder. Smaller spots may be dried by the use of stone st and smoothing irons.

After being spread and rolled as above specified the binder course must be otected from all travel and be kept perfectly clean until the top course s been applied. If any part of the binder course shows a lack of bond, comes loose or broken or gets covered with dirt it must be replaced with oper material, laid in accordance with the requirements given.

The binder course after being properly constructed should be covered imme- tely with the top course. In no case shall more binder be laid during any e day than can be covered by the top course during the same day. No der course should be left uncovered during the night. If it becomes ated with dust or dirt when left so uncovered it must be swept clean or placed with proper material as the Engineer may direct, before any surface urse is applied thereto.

(*b*) Surface.—Special care must be used in spreading and raking the wear- surface if porous spots, depression or projections are to be eliminated. r this purpose the Contractor shall employ not less than (3) rakers for ch one hundred (100) square yards of surface pavement laid per hour. ditional rakers must be employed when a greater quantity of pavement is ng laid per hour.

The rolling of the wearing surface mixture must be so executed that porous ots will be eliminated, the formation of waves and depressions prevented d the required density and surface finish secured.

Whenever the pavement is laid along side of brick or concrete gutters, eet car tracks, man-hole heads or liners, the finished surface adjacent to em shall be left one-quarter (¼) of an inch higher in order to provide for

subsequent compression by traffic and to avoid depressions which wou otherwise be liable to occur at these points.

9. ROLLING.

After the paving mixtures have been properly spread and raked they sh be rolled as soon as they will bear the roller without undue displacement hair cracking. Delays in the initial rolling of the freshly raked mixtu will not be permitted. In all p aces inaccessible to a roller, such as adjac to curbs, gutters, headers, man-holes, etc., the required compression sh be secured with hot tampers.

The initial and final rolling of the binder course shall be done with a six to eight (8) ton tandem roller or a ten (10) to twelve (12) ton three-wh power roller. The initial rolling of the top course or wearing surface sh be done with a five (5) ton tandem roller, but final compression shall alwa be secured with an eight (8) to ten (10) ton tandem roller or a ten (10) twelve (12) ton three-wheel power roller when the Engineer permits requires the use of this type of roller.

When more than one hundred (100) square yards of wearing surface laid per hour, two (2) rollers shall be kept in use, one of which shall be of finishing size. An additional finishing roller will be required for each ad tional one hundred (100) square yards of wearing surface laid per ho All rollers used shall be kept in good condition and shall weigh not less th two hundred (200) pounds to the inch width of tread. Each roller shall be the charge of a competent experienced roller Engineer and must be kept continuous operation as nearly as practicable. During an 8-hour day ea roller must be engaged in actual rolling for not less than six and one-h (6½) hours, not more than one and one-half (1½) hours being allowed cleaning fires, watering, etc. The ashes from the roller must not be dum upon the binder or wearing surface courses.

The surface of the wheels of the roller must be kept clean at all times a either oiled or wet with water as ordered by the Engineer. When the use water is permitted, it shall not be applied in such quantity that surplus wa will run off of the wheels of the roller onto the pavement.

During the initial rolling of both the top and bottom courses, the ro shall travel parallel to the axis of the pavement, beginning at each edge a working towards the center. Each trip of the roller shall overlap the p ceding one about one-half (½) the width of the roller. Alternate trips the roller should be of slightly different lengths. Subsequent rolling sh be both diagonal and parallel to the axis of the pavement. The rolling sh be continued at the rate of not more than one hundred fifty (150) squ yards of wearing surface per hour for each roller of the finishing size. T roller must not pass off the pavement during rolling, nor stand on the co pleted pavement which has not cooled to normal temperature.

The rolling should be so executed that all parts of the pavement will rece equal compression; also develop any low or high spots caused by impro spreading and raking. The surface of low spots or depressions shall roughened with a hot rake, additional material added thereto and rerol immediately. Excess material shall be removed from the high spots. S repairs should be made as soon after the initial rolling as possible while pavement is yet fairly soft.

10. SEAL COAT.

As soon as possible after the rolling of the mixture is finished and wh the surface is yet fresh, clean and hot, a seal coat of bituminous cement sh be spread thereon. The cement used for this purpose shall be the same used in preparing the pavement mixture. It shall be applied at a tempe ture between 250°F. and 350°F. from a squeegee distributor, and th evenly spread with rubber squeegees. Only sufficient cement shall be u to coat the surface and fill the surface voids without leaving an excess the surface. Immediately over this a top dressing of dustless screenings pea gravel, or a mixture thereof, shall be uniformly spread and rolled i the surface. Some surplus of this dressing shall be left on the surfa

11. SURFACE FINISH.

The surface of the finished pavement must substantially conform to grade and contour specified and shall be free from depressions or projecti which are one-quarter (¼) of an inch above or below the established gra as determined by a straight edge, five (5) feet in length, laid parallel to axis of the road. It must be uniform in density and composition, thoroug bonded together and water tight, and be free from porous or rough sp that will remain wet after the balance of the surface is dry. Such porti

he completed pavement as are defective in finish, or that do not comply ll respects with the requirements of these specifications, shall be taken up, oved and replaced with suitable material, properly made and laid in ordance with the requirements of these specifications at the expense of Contractor.

Joints.

he paving shall be so done that the number of joints required shall be uced to a minimum. When a rope joint is not used the edges of the prev- sly laid pavement shall be cut off in a straight line far enough back from edge to insure that the wearing surface has the required thickness. The shall be made at a slight angle to the pavement surface and present a ooth unbroken edge. The face of the joint shall be painted with bitumin- cement, after which the hot bituminous mixture shall be raked over it to proper depth. Hot smoothers or tampers shall be carefully employed uch manner as to insure the proper bond between the two (2) paving tures without burning or injuring either. The finished joint must be on same plane as the adjacent finished pavement surface. Joints which above or below the general plane of the pavement surface must be brought he proper grade or remade.

he faces of all curbs and gutters, iron castings or other objects projecting ough the pavement shall be painted with hot bituminous cement before adjoining paving mixture is laid. The adjacent paving mixture shall ompressed by ramming with hot tampers when the required compression not be secured with the roller.

Foundation, Condition of.

he foundation, when a bituminous pavement is applied thereon, must dry, clean, free from all frost, and have a temperature above 32°F. at point where the paving mixture is being laid. It must substantially orm to the grade and crown specified, and comply with the requirements n for the type of foundation being used. When a foundation is in the per condition to receive a paving mixture it must be protected from all el that will injure, deface or carry foreign material upon it.

Edge Protectors.

When the edges of pavements are not protected by a concrete or stone or header, four (4) to six (6) inch planks of the same thickness as the shed pavement must be used for this purpose, which shall be firmly ured and left in place until the pavement has been properly rolled and oughly set.

Construction Season.

he pavement shall be laid between the first day of May and the first day December, unless written permission is secured from the Department to pavement at any other time. No pavement shall be laid when it is rain- or when the atmospheric temperature is below 32°F., or when the weather uch as to make it very difficult to lay the paving mixture in a manner ch will permit the proper density and surface finish being secured.

Workmen.

he workmen employed by the Contractor must have had sufficient erience in the preparation of bituminous paving mixtures and the con- ction of bituminous pavements to be able to operate the equipment in n a manner that the pavement produced will have the required composi- ., density and surface finish. The men operating the mixing plant, the eaders, rakers and roller men must show by the work completed that they e had the necessary experience and are making the proper effort to exe- e the work in the manner required by these specifications. Otherwise, r services will have to be dispensed with by the Contractor.

Plant and Equipment.

he plant used in preparing all bituminous paving mixtures must be of the ch type, capable of mixing in the manner herein specified not less than (10) tons of the paving mixture for each mixer per hour, and must be vided with separate chambers for heating and mixing the ingredients. direct heat except steam shall be applied to the exterior surface of the ing chamber or flame through the same. The aggregate shall be heated revolving kiln. The heat must be so regulated that the aggregate can ly be heated to and maintained to the required temperature. The tem- ature of the uncoated heated aggregate shall be determined by an electric ometer, so placed at the discharge chute of the dryer as to register omatically the temperature thereof.

All mixing plants which do not dry and heat the aggregate in unit bat must be equipped with a twin-pug mixer, rotary screen, storage bins, ho and scales.

The rotary screen must separate the aggregate into two or more s exclusive of tailings. This screen must be not less than five (5) feet in le and contain the size openings necessary to produce a paving mixture of composition herein specified.

The main bin into which the hot screened aggregate falls must be divi to correspond to the different sized openings in the rotary screen, and b arranged that the aggregate from each size screen will pass into its respec bin without getting into the adjacent sub-bins. Each sub-bin must provided with an overflow that will prevent excess material being accu lated in any one sub-bin. An overflow must also be provided to pre all material larger than that permitted to be used in the pavement u construction from falling into any of the bins.

Each sub-bin must have a separate outlet with a gate at the bottom, an arranged that any definite quantity of aggregate can be drawn theref The hopper into which the hot aggregate is drawn must rest upon a se scales so arranged that any definite weight of material can be weighed of each sub-bin.

The mixer must be capable of holding and properly mixing at least a thousand (1000) pound batch of paving mixture. Each plant, regar of the type of mixer used, must have at least two asphalt kettles holding less than six hundred (600) gallons each, and an asphalt thermomete use therewith. The heat must be applied to these kettles in such a ma that the asphalt cement will be uniformly heated without being burne decomposed.

The asphalt carrier used to measure and apply the asphalt cement r be balanced upon a set of scales. It shall be so arranged that the asp cement can be easily and quickly weighed and poured in a thin sheet bet the two lines of paddles the full width of the mixer.

When a squeegee distributor is required to be used, it must be designe this particular purpose. All equipment and methods used in the prepara and construction of the pavement must be approved by the Engineer b being used on this contract.

18. Field Laboratory.

The Contractor shall provide and keep in good order at the plant the lowing testing equipment which may be used by the Engineer or Inspe

1 Penetration Machine Complete with Dishes, Thermometer, Nee Stop Watch, etc.

1 Laboratory Sand Scale, 500-gr. capacity.

1 Set 6- to 8-in. Sieves, containing the following: Sizes 10, 20, 30, 40 80 and 200 meshes, with bottom pan and cover.

1 Set 6- to 8-in. Screens, 1¼, 1, ¾, ½ and ¼ in.

2 6-in. Pointed Trowels.

2 6- to 8-in. Steel Spatulas.

2 Brushes.

2 Or more Inspectors' Armor Asphalt Thermometers.

1 Roll Pat Test Paper.

The above equipment must be standard type and approved by the Tes Engineer. The Contractor shall also provide a field laboratory in whic house and use the above equipment, said laboratory to be not less than (10) feet wide, twelve (12) feet long and seven (7) feet high, floored, con not less than two windows and work bench with the necessary drawers; laboratory to be used exclusively for testing purposes by the Contra Engineer or Inspector.

Surface Type S. A.

75C. SHEET ASPHALT

Two Course

1. Definition.

A sheet asphalt pavement is one in which the wearing surface is comp of bituminous sand and mineral filler, bound together with an asph cement. It is usually laid in two courses—the top or wearing surface the bottom or binder course.

2. Thickness and Weight.

The top course must have an average thickness after ultimate compres of not less than one and one-half inches (1½"), shall not be less than

d one-quarter inches (1¼″) nor more than two inches (2″) thick at y one point, and shall have an average weight of not less than one hundred ty (150) pounds per square yard.

The bottom course shall have an average thickness after ultimate com- ession of not less than one and one-half inches (1½″), shall not be less an one and one-quarter inches (1¼″) nor more than two and one-half :hes (2½″) thick at any one point, and shall have an average weight of t less than one hundred seventy (170) pounds per square yard.

Materials Required.

The top or wearing surface shall be prepared from bituminous sand, min- al filler and asphaltic cement, Grade LM[1], CM[1], NA[1] or. . . . .

The bottom or binder course shall be prepared from ¾-in. trap rock, dolo- te or. . . . . bituminous sand and asphaltic cement, Grades LM[1], CM[1], A[1] or. . . . .

These materials shall comply with the requirements given in Articles 92, A, 97 and 99.

Composition.

The finished pavement must not vary in composition more than the limits en below:

Screens and sieves		Type of opening	Bottom course		Top course	
Passing	Retained on		Minimum, %	Maximum, %	Minimum, %	Maximum, %
½-in.	1-in.	Circular	0.0	25.0		
in.	½-in.	Circular	40.0	70.0		
-in.	¼-in.	Circular	5.0	20.0		
-in.	10-mesh	Square	00.0	15.0	....	2.0
-mesh	30-mesh	Square	3.0	10.0	10.0	30.0
-mesh	50-mesh	Square	4.0	8.0	15.0	30.0
-mesh	80-mesh	Square	4.0	8.0	15.0	30.0
-mesh	200-mesh	Square	3.0	12.0	12.0	28.0
o-mesh filler	....	Square	0.0	5.0	12.0	20.0
tal stone content—retained on 10-mesh.			75.0	90.0	0.0	2.0
tumen content.			4.0	5.5	10.5	12.5

Estimating Ingredients.

The proportions of the different ingredients required to prepare the pave- ent shall be determined by weight. The pavement must not vary in com- sition more than the specified limits given.

The bitumen content is based upon the finished pavement, exclusive of y mineral or bituminous surface coating applied. The exact amount of neral filler and asphaltic cement to use between the limits defined herein all be determined by the Testing Engineer. In calculating the percent- es of the various sizes of ingredients of which the mineral aggregate is mposed, the bitumen is included. The actual amount of paving mixture ed shall be estimated from the railroad shipping weights of the ingredients ed, batches of paving mixtures prepared and used, or loads delivered and d.

Surface Type A

75L. AMIESITE

Bituminous Concrete

Two Course

Definition.

A bituminous concrete pavement is defined as one which is composed of an stone, bituminous sand and a mineral filler, bound together with tuminous cement.

2. Thickness and Weight.

This pavement shall be laid in two (2) courses; the bottom, or binc course, and the top, or wearing course, in the ratio of not less than two (nor more than three (3) parts of bottom course as one (1) part of top, weight. The finished pavement must be not less than two (2) nor more th three (3) inches thick at any point after ultimate compression, and wei not less than two hundred and fifty (250) pounds per square yard of surfa The thickness of the top course must be sufficient to completely cover t bottom course, and also to eliminate any inequalities in the binder surfa However, in no case shall it be laid over one (1) inch thick after compressic

3. Materials Required.

The pavement shall be prepared from the following ingredients: trap ro dolomite or................, and stone dust, Grade A, hydrated lime, a bituminous cement, Grade NA³, LM³, T³, CM³, or..............

These materials shall comply with the requirements therefor as defined Articles 92 and 99.

4. Composition.

The finished pavement must not vary in composition more than the lim given below:

Screens and sieves		Type of opening	Bottom course		Top course	
Passing	Retained on		Minimum, %	Maximum, %	Minimum, %	Max mum %
2-in.	1-in.	Circular	40.0	70.0		
1-in.	½-in.	Circular	25.0	35.0	....	20.(
½-in.	¼-in.	Circular	0.0	10.0	40.0	55.(
¼-in.	10-mesh	Square	3.0	8.0	15.0	30.(
10	30-mesh	Square	4.0	8.0	8.0	15.(
30	80-mesh	Square	3.0	6.0	3.0	8.(
80	200-mesh	Square	2.0	7.0	2.0	6.(
200-mesh	Filler	Square	2.0	6.0	4.0	8.(
Total stone content—retained on 10-mesh			70.0	95.0	65.0	85.(
Bitumen content.................			3.0	5.0	5.5	8.(

5. Estimating Ingredients.

The proportions of the different ingredients required to prepare the pa ment shall be determined by weight. The pavement must not vary in co position more than the specified limits given.

The bitumen content is based upon the finished pavement, exclusive any mineral or bituminous surface coating applied. The exact amount mineral filler and asphaltic cement to use between the limits defined her shall be determined by the Testing Engineer. In calculating the perce ages of the various sizes of ingredients of which the mineral aggregate composed, the bitumen is included. The actual amount of paving mixt used shall be estimated from the railroad shipping weights of the ingredie used, batches of paving mixture prepared and used, or loads delivered a laid.

6. Preparation.

The quantity of ingredients used per batch in the preparation of the pav mixture must be accurately determined by either weight or measurem depending upon the type of plant and kind of material being used. In eit case the devices used in measuring these ingredients must be standardi whenever so requested, also the maner in which these devices are used sh be demonstrated and the quantity of material thus secured verified, wh ever so ordered by the Inspector or Engineer. The plant used in prepar the paving mixtures shall comply with the requirements given bel

The mineral filler should be so cast into the mixing chamber that it evenly distributed over the surface of the aggregate and not dumped in (

of the mixing chamber. The asphaltic cement should also be added vly in a thin sheet the full width of the mixing chamber. If the filler asphaltic cement are not added in this manner, the time required to duce a uniform paving mixture will be two (2) or more minutes per batch, erwise, from one (1) to one and one-half ($1\frac{1}{2}$) minutes will be sufficient. he mineral aggregate must be perfectly dry when coated and have a perature of not less than 60°F. nor more than 125°F. The bitumen, n applied to the aggregate must have a temperature of not less than °F. nor more than 350°F., and must be free from unmelted lumps. From e (3) to five (5) pounds of hydrated lime shall be used for each ton of ing mixture prepared.

n preparing the paving mixture for both the top and bottom courses, the e and sand shall first be placed in the mixing chamber, after which some efier shall be added, and as soon as the aggregate is coated therewith the haltic cement shall be added. More liquefier shall then be added and mixing continued until the aggregate is completely coated with the haltic cement. The hydrated lime shall then be added, and more lique- if necessary, to secure the proper distribution of the asphaltic cement. mixing shall continue until all particles of the aggregate are completely uniformly coated with the asphaltic cement.

he paving mixture, when properly prepared, must be uniform in composi- , free from lumps or balls containing an excessive quantity of bitumen, n material containing less bitumen than that required, and not show ence of the improper application of the liquefier. The above mixture l not be laid sooner than twenty-four (24) hours nor later than fourteen days after preparation, unless written permission is secured from the ineer to lay the same before or after these intervals.

[AULING AND HANDLING.

he paving mixtures must be kept clean during hauling and handling. se mixtures must not be dumped any faster than they can be properly lled by the shovelers, nor at such a rate that over six (6) tons of paving ure are upon the platforms at the same time. They must be spread ediately after being dumped, and must be kept perfectly clean until ad. Any part of the paving mixture which becomes dirty must be cted. All paving mixture must be carefully removed from the spot n which it was placed before any additional paving mixture is placed eon.

hese paving mixtures may be dumped direct on a concrete foundation, when the foundation is macadam or telford they shall be dumped on al or wooden platforms, which must be of such size that the paving mix- will not fall off when dumped thereon or work off during spreading. wearing surface mixture may be dumped on the binder. However, load of paving mixture must be dumped outside of the area over which it be spread.

l vehicles used in transporting paving mixtures must have tight-fitting oms which will hold hot, thin mixtures without leaking. When motor ks are used the bodies should be insulated for long hauls during cold her so that the paving mixtures adjacent the ends and sides will not me chilled during transit. All motor trucks used for this purpose must dump bodies that will permit the rapid unloading of the mixture. The e surface of these bodies should be oiled just before loading. However, sufficient of this oil shall be used to coat the surface. No pools of oil appear in the bottom of the truck.

PREADING.

Bottom Course.

he paving mixture for both courses must have a temperature of not less 50°F. nor more than 125°F., when dumped on the platforms or when ad, unless written permission is secured from the Engineer to lay the ng mixture when it has a lower or higher temperature than that specified e.

he bottom course shall be so spread upon the foundation that after being d as herein specified, it will be uniform in density and its upper surface have the proper crown and be parallel to the grade established for the ce of the finished pavement.

he time and manner of rolling shall be governed by the condition of the ng mixture. If the paving mixture contains enough liquefier to be soft plastic it shall not be rolled until the bitumen has hardened sufficiently to the pavement the necessary stability when properly consolidated by

rolling. During rainy or cold weather it may require twenty-four (hours or more for the bitumen to cure after the paving mixture has b spread, but during hot, dry weather it may cure sufficiently in from six to eight (8) hours.

When properly cured the paving mixture shall be rolled. The initial r ing shall be continued until the desired bond between the ingredients of aggregate is secured and any porous or low spots disclosed. Depressi made by rolling shall be filled with additional material and rerolled so t the surface of this bottom course will be of a uniform character and have required grade and crown.

After being spread and rolled as above specified, the bottom course m be protected from all travel and kept perfectly clean until the top co has been applied. If any part of this course shows a lack of bond, beco loose or broken up, or covered with mud, it must be replaced with pr material laid in accordance with the requirements given herein. If, be the surface course is applied, it becomes coated or partly coated with d the part thus coated must be swept and then given a light application of b minous cement Grade K, or replaced with proper material as the Engi may direct. When this bituminous cement is used it must be allowe cure before any surface course is applied to the bottom course thus coa If the bottom course becomes wet before it can be covered, it must be allo to dry before the surface pavement is laid.

(*b*) *Top Course.*

After the blttom course has been spread and rolled as above specifi shall be covered at once with the top course. This course shall be spread uniform layer and immediately rolled until it shows no further eviden compressibility.

9. Rolling.

The initial and final rolling shall always be done with 10- to 12-ton t wheel power-driven roller, or a 12- to 15-ton tandem roller. During initial rolling the roller shall travel parallel to the axis of the paven beginning at each edge and working towards the center.

Subsequent rolling shall be both diagonal and parallel to the axis o pavement. The rolling shall be continuous at the rate of not more tha hundred fifty (150) square yards of surface per hour for each roller. roller must not pass off the paving mixture during rolling and the whe the same must be kept clean and oiled at all times. No water shall be ap to the wheels of the roller. Ashes, coal, dirty water or grease must n allowed to drop from the roller onto the pavement.

If porous spots or spots showing compression remain after rolling, mo the top course must be added at such points and firmly rolled into p After rolling has been finished the surface of the top course must hav required crown, density and thickness and be at the grade establishe the surface of the finished pavement. The surface shall then be co with a thin coating of clean, coarse sand or stone dust, using about fi pounds per square yard. After this coating has been applied, the pa the pavement thus covered must be open to travel.

The faces of the curbs, gutters, iron castings and other objects in the ment shall be painted with bituminous cement Grade K before the a mixture is placed against them. The adjacent paving mixture shall be pressed by tamping when it is impossible to properly compress it by ro

10. Surface Finish.

The surface of the finished pavement must be even, uniform, free bumps, waves or depressions that are more than one-quarter (¼) of an below or above the general surface of the pavement as determined by a str edge not less than five (5) feet in length, laid parallel to the axis of the ment. It must be uniform in density and composition, thoroughly bo together, water-tight and have the grade and crown specified or show plans. The paving mixture must be so spread, raked and rolled tha pavement surface will be free from porous or rough spots. When such appear in the surface they must be repaired in a manner satisfactory t Engineer or cut out and replaced with material prepared and laid as h specified.

Portions of the completed pavement which are defective in finish, pression or composition, or which do not comply in all respects wit requirements of these specifications, at the Contractor's expense sha removed, and replaced with material prepared and laid in accordance the requirements therefor as given herein.

FOUNDATION, CONDITION OF.
he foundation, when a bituminous pavement is applied thereon, must be clean, free from all frost, and have a temperature above 32°F. at the t where the paving mixture is being laid. It must substantially conform e grade and crown specified, and comply with the requirements given for type of foundation being used. When a foundation is in the proper lition to receive a paving mixture it must be protected from all travel will injure, deface or carry foreign material upon it.

EDGE PROTECTORS.
hen the edges of pavements are not protected by a concrete or stone or header, four (4) to six (6) inch planks of the same thickness as the hed pavement must be used for this purpose, which shall be firmly red and left in place until the pavement has been properly rolled and oughly set.

CONSTRUCTION SEASON.
he pavement shall be laid between the first day of May and the first day ecember, unless written permission is secured from the Department to pavement at any other time. No pavement shall be laid when it is ing or when the atmospheric temperature is below 32°F., or when the ther is such as to make it very difficult to lay the paving mixture in a ner which will permit the proper density and surface finish being secured.

WORKMEN.
he workmen employed by the Contractor must have sufficient experi- in the preparation of bituminous paving mixtures and the construction ituminous pavements to be able to operate the equipment in such a ner that the pavement produced will have the required composition, ity and surface finish. The men operating the mixing plant, the spread- rakers, and roller men must show by the work completed that they have the necessary experience and are making the proper effort to execute the in the manner required by these specifications. Otherwise, their ser- s will have to to be dispensed with by the Contractor.

PLANT AND EQUIPMENT.
he plant used in preparing the bituminous paving mixtures must be of batch type, capable of mixing in the manner herein specified, not less ten (10) tons of the paving mixture each mixer per hour, and must be rided with separate chambers for drying and mixing the ingredients. direct heat except steam shall be applied to the exterior surface of the ng chamber. The aggregate, when drying is required, shall be heated evolving kilns. The heat must be so regulated that the aggregate can y be heated to, and maintained at, the required temperature.

ll mixing plants must be equipped with a twin-pug mixer, rotary screen, age bins, hopper and scales. The screen must contain the size opening ssary to produce a paving mixture of the composition specified.

he mixer must be capable of holding and properly mixing at least a 1000- batch of paving mixture. Each plant, regardless of the type of mixer l, must have at least two asphalt kettles holding not less than six hundred) gallons each, and an asphalt thermometer for use therewith. The heat t be applied to these kettles in such a manner that the asphaltic cement be uniformly heated without being burnt or decomposed.

he asphalt carrier used to measure and apply the asphaltic cement must alanced upon a set of scales. It shall be so arranged that the asphaltic ent can be easily and quickly weighed and poured in a thin sheet between two lines of paddles and for the full width of the mixer.

hen a squeegee distributor is required to be used it must be designed for particular purpose. All equipment and methods used in the preparation construction of the pavement must be approved by the Engineer before g used on this contract.

FIELD LABORATORY.
he Contractor shall provide and keep in good order at the plant the follow testing equipment which may be used by the Engineer or Inspector.

Penetration Machine complete with Dishes, Thermometer, Needles, Watch, etc.

Laboratory Sand Scale 500-gr. capacity.

Set 6- to 8-in. Sieves, containing the following: Sizes 10, 20, 30, 40, 50, and 200 meshes, with bottom pan and cover.

Set 6- to 8-in Screens, 1¼, 1, ¾, ½ and ¼ in.

6-in. Pointed Trowels.

2 6- to 8-in. Steel Spatulas.
2 Brushes.
2 Or more Inspectors' Armor Asphalt Thermometers.
1 Roll Pat Test Paper.

The above equipment must be of standard type and approved by Testing Engineer. The Contractor shall also provide a field laborator which to house and use the above equipment, said laboratory to be not than ten (10) feet wide, twelve (12) feet long and seven (7) feet high, floc contain not less than two windows and work bench with the necessary d ers; this laboratory to be used exclusively for testing purposes by the (trator, Engineer or Inspector.

Item[1] 51A. Cement-concrete Pavement (1 : 2 : 4); Item 51B Cement concrete Pavement (1 : 2 : 3½ Mix); Item 51C Cement-concrete Pavement (1 : 1½ : 3 Mix)

Item 51A, 51B, 51C and 51D. Cement Concrete Pavement

The general specifications are hereby modified in that

Page 114–115. Forms shall be rounded on the top face to not more ¾ of an inch radius.

Page 118. Where screeding is dispensed with, the reinforcement be supported on approved metal supports.

Page 118. Channel for protecting joints shall be constructed of ı ⅛ inch in thickness.

Page 121. Straw will not be permitted for cover.

Page 121. Sprinkling shall be done with an approved nozzle.

Page 121. When the pipe line necessary for concreting and curing o tions is two miles or less in length, a pipe at least 2½ inches in diai shall be used. When the pipe line is more than two miles in length additional pipe shall be at least three inches in diameter and shall be p adjacent to the source of water supply.

Page 121, Paragraph C. The combined weight of vehicle and load not exceed 10 tons. The total weight of any combined hauling t semi-trailer and load shall not exceed 14½ tons. The load on any one t wheel shall not exceed 2½ tons. All such vehicles and trailers shall be equipped with approved pneumatic or cushion tires. Solid rubber tire not be permitted. Only cushion tires having a hollow section or ai running throughout their entire length will be considered.

Work.—Under this item the contractor shall construct a concrete pave upon a properly prepared fine grade conforming to the lines, grades, and cal sections shown on the plans or ordered by the engineer.

Material.—The concrete pavement shall consist of a mixture of Poı cement, fine and coarse aggregate, measured separately (however, scr gravel or broken slag cannot be used as coarse aggregate unless it is so on the plans or in the itemized proposal).

All material used under this item, such as Portland cement, fine and (aggregate, water, joint fillers, etc., shall meet the requirements given Detail Specifications—Materials of Construction.

Forms.—The forms for this work shall be made of metal of a min length for 10′ for tangents and for curves of a radius of 150′ and moı curves of radius less than 150′ wooden side forms of 2″ well-seasoned sı planks or steel side forms 5′ in length shall be used. These forms sh of a depth equal to the depth of the concrete and steel forms shall h minimum width of 4″ on the base. The material used in manufact metal side forms shall be at least No. 10 gage and a 6″ side form shall at least 6½ lb. per linear foot, including the fastening.

All forms shall be of approved section with a vertical face round the upper corner to not more than ¾″ radius. Forms shall have a connection to insure unbroken lines across the joint.

All forms must be straight, free from bends and warps at all times shall be cleaned thoroughly and oiled before concrete is placed against this cleaning and oiling being repeated daily as the forms are moved a The forms shall rest firmly upon the thoroughly compacted subgrade thr out their entire length, shall be joined neatly and tightly and staked se to line and grade at least 300′ in advance of the point of placing concr using at least three bracing pins or stakes to each 10′ length of side foı

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t they will resist the pressure of the concrete and the impact of the tamper hout springing.

Handling Material.—At no times shall aggregates be piled upon the subde except that stock piles may be located at central point on planks or et plates on the subgrade not less than 1200′ apart. At all times at st 500′ of subgrade in advance of the mixer shall be prepared and kept from all aggregates. When stock piles are located at loading plants or at er distributing points, the materials shall be piled on space that has been perly prepared and the piles shall be of such shape and size that materials y be stored and handled without becoming dirty or mixed with foreign tances. Cement shall be emptied directly from the shipping package into charging skip of the mixer, or it may be transported to the mixer, emptied m bags if covered by the sand or stone required for each separate batch, vided the aggregates are sufficiently dry to prevent any setting action of cement during transportation to the mixer, and provided further that the ck body used to transport the batches is equipped with a waterproof paulin for protection from sudden rain.

Measuring Devices.—Wheelbarrows will not be permitted for measuring regates, when the aggregates are transported by industrial railway or vered to the mixer in trucks, wagon, or carts, they shall be contained in ch boxes of the volumes required by the engineer. Subdivided batch es shall be approved by the engineer before they may be used. All terials measured in batch boxes, cars, trucks, carts, or other containers to be struck off at the point of loading. If batch boxes are used, which not subdivided to give the exact volumes of each of the aggregates, the terials shall be measured, separately and accurately, by approved means ore being placed in these batch boxes. Forks shall be used when handling rse aggregates from the ground. The mixer shall be equipped with a ing device which will automatically lock the discharge lever during the time of mixing and release it at the end of the mixing period. During progress of the work, should the timing device become broken, or out order, the contractor will be permitted to operate while same is being pared, provided each batch is mixed 1½ min. and provided repairs are de promptly. The mixer shall be equipped with an accurate automatic er-measuring device. No mixing will be permitted when valves are king or otherwise out of order. When bulk cement is used, the cement st be proportioned by weight. No volumetric proportioning of cement be permitted.

Composition.—Under Item 51A the concrete shall be composed of 1 part Portland cement, 2 parts of fine, and 4 parts of coarse aggregate measured arately.

Under Item 51B the concrete shall be composed of 1 part of Portland ment, 2 parts of fine, and 3½ parts of coarse aggregate measured separately.

Under Item 51C the concrete shall be composed of 1 part of Portland ment, 1½ parts of fine, and 3 parts of coarse aggregate measured arately.

The proportions of coarse aggregate, only, may be varied by the engineer, the total amount of coarse aggregate shall not be varied by more than % from the amount indicated.

Consistency.—When the pavement is finished by hand, sufficient water ll be used in mixing to produce a concrete which will quake when deposited place, but not enough to cause it to flow.

When the pavement is machine finished only sufficient water shall be d so that when the concrete is dumped on the subgrade it will cone up l quake. The quantity of the water shall be determined by the engineer l shall not be varied without his consent.

Mixing Conditions.—No concrete shall be mixed while the air temperature it or lower than 40°F. and no materials containing frost shall be used. ment or fine aggregates containing lumps or crusts of hardened materials ll not be used. The concrete shall be mixed only in such quantity as is uired for immediate use, and any which has developed initial set or has n mixed longer than 45 min. shall not be used. No concrete is to be ced on a frozen subgrade.

Mixing Concrete.—All equipment necessary for the laying of pavement st be on hand and must be inspected and approved before concreting rations are begun by the contractor. Concrete shall be mixed thoroughly a batch mixer of an approved type and capacity for a period of not less n 1 min. after all material is in the drum, and during this period the m shall make not less than 12 nor more than 18 r.p.m.

The entire contents shall be removed from the drum before materials placed therein for the succeeding batch. The mixer shall be equipped w an approved boom and bucket discharging device.

Placing Concrete.—Before any concrete may be placed, each sectio the subgrade must be checked with a standard "subgrade tester" approved, this operation being continued as the work progresses, a stanc "subgrade tester" being kept in place on the forms at the discharge en the mixer at all times. Loose, dry material shall be thoroughly tam into the subgrade and all soft or objectionable material be removed from subgrade before any concrete is placed. Concrete shall be placed only moist subgrade. If the subgrade is dry it shall be sprinkled with as m water as will be absorbed readily. Where the pavement is to be laid adja to railway tracks or around structures, concrete shall not be placed until tracks and structures have been set to the required grade and alignmer advance, and all structures which project through the pavement sha cleaned thoroughly to permit adhesion of the concrete.

During placing of the concrete pavement, a roller, weighing not less t 5 tons, shall be maintained in readiness to reroll the fine grade if the sur for any reason has become uneven or defective.

The concrete shall be laid on not more than one-half of the width of p ment at one time. An interval of at least 7 days shall elapse between pla parallel adjacent slabs of pavement. All edges shall be protected by pl ing or other approved method where traffic is permitted prior to comple of the full pavement width.

The concrete shall be deposited on the subgrade in successive bat directly from the mixer, by means of an approved boom and bucket disch ing device. Concrete shall be distributed to the required depth and fo entire width of the slab by shoveling or any approved method which preserve the integrity of the mixture. However, in no case shall rak used for distributing concrete. Concrete shall be thoroughly spaded a all joints and on the inside of forms.

Where the pavement is reinforced, the reinforcement shall be sec held in place to insure its being in the prescribed position after the con has been poured. The concrete shall be struck off by means of a temp to the required depth below the surface of the finished pavement befor reinforcement is placed, except that screeding may be dispensed provided the reinforcement is held in its prescribed position by any c method acceptable to the Deputy Commissioner.

Forming Joints.—Joints shall be formed where shown on plans c directed by the engineer. They shall be perpendicular to the surface of pavement for the full depth of the section and extend in a straight line.

Expansion joints may be of either the permolded or poured type, me requirements of the Detail Specifications—Materials of Construction.

Pins for staking joints and bulkheads shall be ¼″ steel 12″ long and be left in place in the pavement.

Bulkheads shall conform to the section of the pavement, shall be steel, shall be cleaned each time used, and shall be straight and smooth.

Premolded transverse joints shall be ½″ in thickness and shall extenc above the surface of the pavement.

Premolded longitudinal joints shall be flush with the true surface o pavement and shall be the thickness shown on the plans.

Transverse expansion joints shall be ½″ in thickness, normal to the ce line of pavement, and in a straight line across the full width of the paven These joints shall be spaced 40′ apart, unless otherwise shown on the p and shall also be formed whenever it is necessary to stop concreting. due to any emergency, concreting must be stopped within 10′ after for a transverse joint, the contractor shall remove the concrete to the previously formed and no payment will be made for placing or removin

The concrete along all joints shall be carefully compacted and finishe a true surface, a split float being used for transverse joints. All joints be tested with a 10′ straight-edge or template immediately after forming any variation from the true surface shall be immediately corrected. J shall be open on the edges for their entire depth upon the removal o forms.

Where the pavement is constructed continuously across a bridge or cul whose floor is below grade, transverse joints shall be formed at such dist from the abutment as to insure a bearing at the ends of the slab of not than five feet beyond the limits of the backfill area.

Vhere the pavement joins a bridge or culvert, whose floor is at grade, nsverse joints shall be formed at the back of each abutment and also at h distance from the abutment as to give a bearing at the end of the slab not less than five feet beyond the limit of the backfill area.

Premolded transverse joints shall be formed by staking a bulkhead urely in place by means of a row of pins driven on each side, 2′ apart and below the surface of the pavement alongside of which the premolded it shall be placed and securely staked by one row of pins driven 2′ apart 2″ below the surface of the pavement. When the concrete has been ced on both sides of the bulkhead and struck off true to the surface, the khead shall be carefully removed.

Poured joints shall be formed by staking a temporary joint, of a type roved by the Deputy Commissioner, securely in place by means of a row ins driven on each side 2′ apart and 2″ below the surface of the pavement. se temporary joints shall be left in place until ready to pour the joint.

inishing Concrete.—Competent concrete finishers shall be employed at times. The surface of the concrete shall be struck off by means of two eds (*i.e.*, a steel template or steel-shod wooden template) at least 6″ vidth weighing no less than 15 lb. per linear foot. The templates shall at least 2′ longer than the width of the pavement slab, shall be shaped the surface of the pavement and have sufficient strength to retain their pe under all working conditions. The first screed shall be used as a nbination tamp and screed, sufficient tamping to be done to thoroughly npact the entire mass of the concrete and the screed carried back and ved forward with a longitudinal and crosswise movement. The screed ll not be lifted from the form during the screeding process. Concrete ll pile up in front of each screed, during the screeding process, for its length at all times.

'he second screeding shall follow in close succession to the first, care being en to keep the screed bearing directly on the side forms at all times and to ure a smooth and even surface.

After the screeding has been completed the concrete shall be finished by ng a belt of wood or canvas not less than 10 nor more than 12″ in width. se belts shall not be less than 2′ longer than the width of the pavement. belts shall be worked with a longitudinal and crosswise motion, care ng taken not to permit the edges to dig in the surface of the concrete or to k the crown out of the pavement.

Belting shall be repeated until all surplus water is removed from the face.

When an approved finishing machine is used, an experienced operator, isfactory to the engineer, must, at all times, be in charge of the machine l a complete hand-finishing outfit must be provided in case of breakdown. Necessary hand finishing of joints and surface irregularities shall be done, h a wooden float, from a bridge which shall not rest on the concrete at point. All ends and edges of the concrete slab shall be rounded with an proved edging tool, to a radius of approximately ½″.

The surface of the pavement shall be tested, immediately after finishing, h the standard 10′ straight-edge laid parallel with the center line of the ement and any irregularity exceeding ¼″ shall be immediately corrected the satisfaction of the engineer.

After the pavement has been completed the surface shall be given a om finish, the broom being drawn across the surface in not more than stroke per width of broom.

Premolded transverse joints shall be trimmed, with an approved tool, ore cover coat is applied and any irregularity in the adjacent pavement ll be immediately corrected in a manner satisfactory to the engineer.

Forms shall not be removed until the day after the concrete is placed.

Protection of Concrete.—Vehicular traffic shall be excluded from the crete by the erection and maintenance of substantial barricades, for a iod of at least 21 days after laying, or longer if so desired.

When ordered by the engineer, temporary crossovers, consisting of a layer of suitable soil free from stone and a 3″ plank roadway 16′ wide urely held in place, shall be constructed at all street and road intersections accommodate traffic. The concrete shall be protected as follows:

. During threatening weather the concrete shall be protected with canvas soon as it is finished. Sufficient canvas to cover 200 lin. ft. of pavement, shall be provided and available for immediate use.

. The concrete shall be protected with two layers of burlap laid directly the pavement as soon as it has hardened sufficiently so that the burlap

will not adhere. The strips shall overlap not less than 6″ and burlap r be thoroughly wet when placed, and kept wet by spraying until covering be placed. Sufficient burlap to cover at least the pavement laid in a si day must be provided. The burlap shall be kept wet until removed.

Immediately after the burlap is removed the entire surface of the paver including edges and sides, shall be wetted thoroughly and covered with straw, or other approved material of a like nature to a depth of not less 6″, which covering shall be kept wet by sprinkling with water for at 10 days. The covering material shall remain on the pavement for a pe of 18 days or, under favorable conditions, for a shorter period as dire by the engineer, after which the covering shall be removed, the paver swept clean, and the concrete allowed to cure for 3 days more before roadway may be opened to traffic.

The ponding method may be used, in which case the contractor must the surface flooded by at least 2″ of water for a period of 10 days.

c. The general specifications, par. C, are hereby modified in that combined weight of vehicle and load shall not be more than 10 tons that the total weight of any combined hauling truck, semitrailer, and shall not exceed 14½ tons and the load on any one trailer wheel shall exceed 2½ tons.

All such vehicles and trailers shall be fully equipped with approved p matic or cushion tires. Solid rubber tires will not be permitted. (cushion tires having a hollow section or air core running throughout entire length will be considered.

d. During cold weather, concrete shall be protected with a canvas cc supported above the surface of the pavement on approved frames, so the canvas will not rest upon the surface of the concrete. When the conc has hardened sufficiently, the canvas cover and frame shall be removed the surface of the pavement shall be covered with straw or other appro material to a depth of not less than 6″. It shall remain in place not than 3 days, after which it may be removed and other cover material app

In cold weather or when required or approved, other methods of cu and protection may be used. Any concrete laid during cold weath done at the contractor's risk and damaged sections of concrete mus removed and replaced by him at his own expense.

Sealing Joints and Maintenance of Cracks.—All expansion and cons tion joints and all cracks shall be sealed before the pavement is open to tr and just prior to discontinuing operation when the work is suspe during the winter and just previous to acceptance. The joints and cr shall be cleaned thoroughly, and, when they are dry, hot, bituminous mat shall be poured into them, care being exercised to prevent the bitumi material from spreading over the surface of the pavement for a widt more than 1″ on either side of the joint. The bituminous material then be covered with coarse, dry sand. This bituminous material shall the requirements of the specifications for Bituminous Material, A, pene tion method.

Measurement and Payment.—The quantity to be paid for under item shall be computed by multiplying the cross-section of concrete p ment, as shown on the plans or ordered by the engineer, by the total le of pavement measured along the axis of the pavement, making no deduct for catch basins and manholes.

The Bureau may take cores from the finished concrete pavement prev to acceptance in order to determine its quality and thickness.

This work will be paid for at the contract unit price per cubic yard cement-concrete pavement under which the contractor shall furnish place all materials (except Portland cement and metal reinforcement) ne sary to complete the concrete pavement. The price bid shall cover mixing, placing, screeding, finishing, and curing of the concrete, furnis and placing of forms, expansion joints, crossovers, material for filling cra etc., and all other labor, material, and appliances necessary to secu perfect concrete pavement.

NEW YORK STATE SPECIFICATIONS

Item 60—Asphalt Block Pavement.—Approved Trap Rock
Item 60A—Asphalt Block Pavement.—Approved Limestone

60.1. **Work.**—Under this item the Contractor shall furnish and p upon a properly prepared foundation asphalt block of the quality spec where shown upon the plans or ordered by the Engineer. This paven

be placed upon the old macadam, old concrete pavement, new concrete lation or on other foundations as ordered by the Engineer and shown the plans.

2. **Material.**—The blocks shall be 5″ in width, by 12″ in length, by 2″ pth, and a variation of more than ¼″ in length or ⅛″ in width or depth these dimensions will be sufficient ground for rejecting any block.

3 The blocks shall consist of the following materials:

Asphaltic cement.

Approved crushed trap rock [item 60], or approved crushed limestone 60A].

Inorganic dust.

e asphaltic cement shall have the following characteristics:

It shall be free from water.

The various hydrocarbons composing it shall be present in a homoge- s solution.

It shall have a specific gravity at 77°F. of not less than 0.99.

It shall have a penetration (77°F., 100 g., 5 sec.) of not less than 15 nor than 25.

It shall have an evaporation loss of less than 2 per cent. The penetra- (77°F., 100 g., 5 sec.) of this residue shall be at least 50% of the original ration.

Its solubility at air temperature in carbon disulphide, for the following d products, shall be at least 99.5% for pure bitumen products, 95.0% ermudez products, 81.0% for Cuban products and 66.0% for Trinidad ıcts.

The solubility of the bitumen, at air temperature, in 76°B. paraffin leum naphtha distilling between 140°F. and 190°F. shall be between 65 o %.

The bitumen, shall show between 8 and 18% fixed carbon.

It shall show an open flash not less than 375°F.

It shall not contain more than 4.7% paraffin scale.

It shall show a toughness at 32°F. not less than 10 cm. Toughness is mined by breaking a cylinder of the material 1¾″ in diameter by 1¾″ ight in a Page impact machine (A. S. T. M., 1908). The first drop of ammer being from a height of 5 cm. and each succeeding blow increased cm.

It shall have a ductility at 77°F., of not less than 8 cm. (Dow mold).

All asphaltic cement will be sampled by an Engineer of the Depart- of Highways and samples sent to the Bureau of Tests, Albany, N. Y.

e crushed rock for coarse aggregate used in the blocks shall be crushed clean hard rock and shall not contain any soft ingredients. It must be ed so that every particle will pass a screen of ¼-in. mesh.

e inorganic dust, or filler, shall be produced from sound limestone, and be powdered to such a fineness that all of it shall pass a 30-mesh sieve ıot less than 50% of it shall pass a 200-mesh sieve. Sufficient inorganic shall be used to give a minimum percentage of voids in the block, and de a sufficient medium for absorbing the asphalt cement.

4. **Block Composition.**—The block composition shall yield not less 8, nor more than 11% of bitumen, when extracted with carbon disul- :.

e mineral aggregate of the blocks shall meet the following mesh analyses:

ng No. 200 sieve at least, %	18.0
ng No. 80 sieve, retained on No. 200 sieve, %	12 to 18
ng No. 40 sieve, retained on No. 80 sieve, %	8 to 14
ng No. 20 sieve, retained on No. 40 sieve, %	8 to 16
ng No. 10 sieve, retained on No. 20 sieve, %	15 to 20
ng ¼-in. sieve, %	100

e use of dust coated screenings will be cause for rejection. The blocks receive a compression in the moulds of not less than 200 tons.

e blocks shall have a specific gravity of not less than 2.45 for trap blocks, 60]; or not less than 2.30 for approved limestone blocks, [Item 60A]. er having been dried for 24 hours at a temperature of 150°F., the blocks not absorb more than 0.75% of moisture when immersed in water for 7 s.

e average penetration of a block shall not exceed ¼″ when tested for 1 at a temperature of 100°F. with a cyliner ¼″ in diameter loaded with 4 o.

60.5. **Method.**—Upon the foundation shall be spread a bed of the ness shown upon the plans, composed of 1 part portland cement and 4 sand, thoroughly mixed with sufficient water to make a stiff paste.

This mortar bed shall be struck with a template to a true surface, e: parallel to the top of the proposed pavement surface and 2″ bel

The blocks shall be laid while the mortar is fresh and before it has be harden. All depressions and other irregularities in the surface sh corrected by the Contractor immediately.

The blocks shall be laid by the pavers standing upon the blocks al laid and not upon the bed of mortar.

The blocks shall be laid at right angles with the line of the street, a such a manner that all longitudinal joints shall be broken by a lap of ap mately four inches. The blocks shall be so laid as to make the lateral as tight as possible, consistent with keeping a good alignment of the c across the street. When thus laid the blocks shall be immediately cc with clean, fine sand, perfectly dry, and screened through a ⅛-in. s This sand shall be spread over the surface and swept into the joints a allowed to remain on the pavement not less than 30 days, or until the of the traffic on the street shall have thoroughly ground the sand in the joints.

On grades, curves or elsewhere as shown on the plans or as ordered Engineer, blocks containing an imbedded anchor of iron or steel of an app shape shall be furnished. Steel strips, 1½″ wide, ⅛″ thick and fror 4′ long may be set on edge between courses as a substitute for anchor b These anchor blocks or steel strips are to be laid in such courses and a intervals as shown on plans or as directed by the Engineer. Payme imbedded metal in anchor blocks or for steel strips will be made und item "MISCELLANEOUS IRON AND STEEL."

60.6. The materials incorporated into blocks shall be approved b Engineer, and samples of all materials shall be sent to the Bureau of and they shall pass the tests required by this Bureau for these mat

60.7. The methods of work and materials used shall at all times be s to the inspection and supervision of the Engineer or his representativ the work.

60.8. **Measurement and Payment.**—The quantity to be paid for und item shall be the number of square yards of asphalt block laid in acco with the plans or as directed by the Engineer. The price bid shall co furnishing and placing of all materials, (except PORTLAND CEMENT), bed, and all labor and incidental expenses necessary to complete the Where placed upon old concrete foundation or upon old macadam the aration of the foundation to receive the mortar bed will be paid for item "CLEANING EXISTING PAVEMENT" or item "SCARIFYING AND R ING OLD MACADAM."

47.14. **Measurement and Payment.**—The quantity to be paid for this item shall be the number of cubic yards of concrete foundatic edging for pavement incorporated in the work in accordance wi plans or as directed by the Engineer.

The price bid shall cover the furnishing and placing of all form materials, (except Portland cement) all mixing, tamping, finishing a labor, appliances, and incidental expenses necessary to complete the The amount to be estimated shall be computed by multiplying the section of concrete foundation and edging as shown upon the plans or c by the Engineer by the total length of concrete foundation and edging ured along the axis of the pavement, making no deductions for catch and manholes.

ITEM 61—BRICK PAVEMENT.—TYPE 1

ITEM 61A—BRICK PAVEMENT.—TYPE 2

61.1. **Work.**—Under this item the Contractor shall furnish and the number of square yards of brick pavement required in accordanc the plans or as ordered by the Engineer. The item will cover the fur and placing of all the brick, cushion, grout, expansion joints and all ma labor and other expenses incidental thereto but will not cover the cc foundation, edging, curbing, manholes, catch basins, etc., which will b for under the especially designated items therefor.

61.2. **Material.**—All bricks or blocks used must be annealed and esp burned for street paving and of the very best quality as regards ha dimensions, toughness, straight lines and non-absorption of water.

ll brick must be neatly piled outside of the neat lines of pavement and the ıping of brick will not be allowed.

ı.3. The paving bricks shall be subjected to abrasion tests conducted by Commission in the manner and with rattlers of the type adopted Febru- 7, 1911, by the National Paving Brick Manufacturers Assocation. One ple of bricks shall be taken and tested for every two hundred thousand ›,000) bricks and less than this when conditions warrant. An average in weight in a rattler test exceeding twenty-four (24) per centum, or an ·age absorption of three and one-half (3½) per centum of water shall cause rejection of the total quantity that the test represents, provided, however, if permitted the bricks may be carefully reculled, and new samples ›n and tested. If this second test passes the requirements, the bricks esented by it may be used. If this second test fails, no further test l be permitted but the entire lot shall be rejected. To insure the furn- ıg of bricks of uniformly acceptable quality, if any "brand" of brick of :h three lots, each of ten thousand (10,000) bricks or more, offered con- tively for acceptance tests, fail to meet the requirements for this section ıout reculling them, then this brand shall be rejected.

ll the above tests will be made by the Bureau of Tests of the State Com- ion of Highways.

:.4. On grades of 5 per cent or over an approved special form of block ıble for steep grades shall be used.

: 5. The size of the brick shall be 3½″ in width by 4″ in depth by 8¾″ ›ngth, unless otherwise shown on plans, and shall not vary from the ›nsions specified more than ¼″ in width or more than ⅛″ in depth nor › than ½″ in length. Bricks of a given brand shall not vary among ıselves more than ¼″ in depth nor more than ⅛″ in width nor more than in length in any one shipment. If the edges are rounded the radius not be greater than 3/16 of an inch. One side shall contain lugs of such ›nsions that transverse joints will not be less than 3/16 of an inch nor more ı ¼″ in width. Each end shall contain a semi-circular groove of ⅛- to radius, or a bulge of at least 1/16″. The grooves shall be horizontal, shall match perfectly when the bricks are laid in the finished pavement. ks in any course shall not vary in width by more than ⅛″.

:.6. Not less than 10 days after the concrete foundation has been com- ›d, there shall be laid a bed of clean Cushion Sand as described under ıterials of Construction," which shall be 1″ thick after being rolled with ller weighing 150 lb. per foot of width. Before being rolled this bed of l shall be brought to the proper elevation and crown as shown on the s by a template of a shape and size satisfactory to the Engineer. After g rolled all irregularities of the surface shall be eliminated and the sand ion shall be brought to the exact form and section by the use of lutes or l templates.

:.7. Premoulded longitudinal expansion joints shall be placed alongside curb or edging, and shall conform strictly to the requirements given ›r "MATERIALS OF CONSTRUCTION."

hese joints must extend to the depth of the brick. No transverse ts shall be allowed. The material should be made into strips of suitable th and of the required depth and thickness as shown on plans and should ıid in the pavement with the ends closely joined as the brick sare beinglaid.

:.8. On the sand cushion prepared as in section 61.6 the bricks shall be fully set on edge with the best edge up, shall be laid straight and at right es to the edging line, except at road intersections, where they shall be at such angles as directed by the Engineer. All brick shall be laid with lugs in the same direction, joints shall be close and at right angles to the and sides. Each alternate course shall be commenced with a half brick. › half bricks or bats shall be used except at the ends of courses, and no shall be less than 3″ in length and at right angles to the courses. All :s shall be broken with a lap of not less than three (3) inches.

hen laying brick on a street or road used in conjunction with a traction pany the courses shall be started at the rails and laid down toward the ·s or edgings.

l brick shall be clean when placed in the pavement. Brick which in the ion of the Engineer are not satisfactorily clean, shall be washed before g placed.

ı no case shall the sand cushion in front of the pavement be disturbed or :ed on during the laying of the bricks.

:.9. After a sufficient number of bricks have been laid, all soft, broken or y misshapen bricks shall be marked by the inspector and removed by the

Contractor. Any bricks slightly spalled or kiln-marked shall be turned and should the opposite face be acceptable, it may be replaced in the ments otherwise, it must be removed.

In laying brick pavement, the inspector shall keep the bricks culled, the Contractor shall make the necessary changes and replacements so the work shall at all times be ready for grouting within 300 ft. from brick-laying.

61.10. After all objectionable bricks have been removed from the ment and all replacements have been made, the pavement shall be swept and thoroughly rolled with a self-propelled tandem roller weighing not 5 tons and not less than 3 tons. Horse rolling shall not be permitted. rolling shall start along the outside edges and progress toward the center shall then be rerolled diagonally both ways until the surface is even. final rolling the pavement shall be tested with a 10′ straight edge laid pa with the curb, and any depression exceedingly ¼″ shall be corrected brought to the proper grade. All bricks disturbed in making replacemen correcting depressions shall be settled into place by ramming or by rero All gutter bricks must be brought to grade by ramming.

This rolling shall start along the outside edges and progress toward center as slowly as possible. After the first passage of the roller, the may be quickened. Portions of the pavement inaccessible to roller sha tamped to grade by the use of hand tamper applied upon a 2″ b

If during or after the rolling of the pavement the sand cushion shall up between the brick more than ¼ their depth, the brick shall be take and the sand cushion again rolled until firm enough to support the weig the brick and roller. After final rolling all broken brick must be repl

Each section of pavement must be acceptable to the Engineer befor grouting on that section may be commenced.

61.11. **Grout.**—Grout for filling the joints of brick or block paven shall be composed of 1 part Portland cement and 1 part group sand, if mixed, and 1 part Portland cement and 2 parts group sand if machine m

61.12. The box for hand mixing this grout shall be about 4′ 8″ 2′ 6″ wide and 1′ 2″ deep, supported on legs of different lengt order that the mixture shall readily flow to the lowest corner, which sha be more than 6″ above the pavement. Any approved mechnical grout may be used.

61.13. If hand mixed, the material, not exceeding 1 sack of cement tog with a like amount of sand, shall be placed in the box and mixed dry, unt mass assumes a uniform color. Water shall then be added, forming a l mixture of the consistency of thin cream for the first coat and sli thicker for each succeeding coat. From the time the water is applied the last drop is removed and floated into the joints of the pavemen mixture must be constantly agitated.

61.14. **Spreading Grout.**—The brick shall be wet to the satisfaction Engineer before any grout is placed. The grout shall be removed fro box to the street surface with a scoop shovel and immediately swept int joints, the mixture in the box being constantly agitated while this is done.

If a mixer is used, as soon as the grout is deposited upon the surfa must be swept into the joints. The work of grouting shall proceed fo entire width of the pavement, working from the sides toward the ce When sufficient time has elapsed for the grout to thoroughly penetra the joints, but before the grout has begun to harden, the section treated be gone over a second time in the same manner, care being taken to oughly fill all joints to the bottom and flush with the top of the brick necessary to secure flush joints, a third, fourth or fifth coat of the grout be swept in and smoothed off with a suitable squeegee. The squeegee in all cases be worked at an angle of 45° with the joints.

Care shall be taken to so conduct the grouting that no part of any join receive an application of the second grout until the first is satisfactorily pleted, nor of the third until the second is completed, etc. To insure result metal strips ¹⁄₁₆″ by 6″ by 3′ must be inserted, for the full length joint, at work intervals; all of the several applications of grout mu completed up to this joint before any grouting is begun on the other side

61.15. **Covering.**—After the joints are thus filled flush with the top bricks and sufficient time for hardening has taken place, the pavement then be sprinkled, shortly after which 1″ of suitable material shall be sp evenly over the entire surface, and be kept moist for a period of at lea days and until the grout has thoroughly hardened.

ıring this period the section grouted must remain absolutely free from rbance or traffic of any kind. Before opening for traffic this cover coat be completely removed.

.17. **Plastering Rail.**—Wherever railway track is encountered in the area paved, the rails shall be plastered with a stiff mortar mixed, 1 part of and cement to 3 parts of concrete masonry sand. This shall be used to letely fill under the head of the rail on both sides of the web. When this ıe no deduction will be made from the paved area for the area of the rails urposes of payment.

18. **Measurement and Payment.**—The quantity of pavement to be for under this item shall be the number of square yards placed in accord- with the plans or directions of the Engineer, and shall be computed by plying the actual width of pavement, including expansion joints, by tal length of pavement measured along the axis of the road and parallel surface, except that the area of manhole covers and catch basins, where ıntered, shall be omitted. The price bid per square yard shall cover and cushion, paving brick, grout, (except Portland Cement), material ‹pansion joint, sand covering, sprinkling, and all other labor, materials ncidentals necessary to satisfactorily complete the work.

Item 61—A

e specifications for this item will be the same as those given under Item d entitled "Brick Pavment, Type 1," except in the following details: ment-sand Bed.—Not less than 10 days after the concrete foundation een completed, there shall be spread upon this foundation a bed of ıt and concrete masonry sand, consisting of 1 part cement and 4 parts ıcrete masonry sand of which the depth shall not be greater than 1″ rolling. The sand and cement must be thoroughly mixed dry before ıg either by an approved type of mixer, or by hand, on a mixing board or The materials shall be thoroughly mixed until a uniform color is ned and should be spread on the foundation in this condition. The ıt-sand bed shall be struck off with a template and be brought to the form and section shown on plans to the required depth below the fin- grade. After the bed has been leveled off it shall be rolled with a roller weighing about 300 lb. If any depressions develop they shall be in and the bed again leveled and the rolling shall be repeated as many as are necessary to compress the sand bed. Tramping upon the ıt-sand bed is prohibited. The inspector must keep the brick culled he Contractor shall make the necessary changes and replacements so the work at all times shall be ready for the grouting within 100 ft. of rick line.

brick laid must be rolled ready for grouting at the end of the working l and each day's work must be completed in full.

ore the grouting is applied the rolled bricks shall be thoroughly wet by ‹ling. It is important that the bricks be well wet so as to set up the ıt-sand bed. An excess of water over that required and taken up by the ıt-sand cushion must not be used. The operation of grouting will be ved as for "Type 1."

yment will be made as for "Type 1" except that it will also cover the ıt-sand bed (except Portland Cement).

Item 59—Wood Block Pavement

(New York State 1922)

1. **Work.**—Under this item the Contractor shall furnish and place upon perly prepared foundation wood block of the quality specified where ı upon the plans or ordered by the Engineer.

s pavement shall be placed upon the old macadam, old concrete pave- new concrete foundation or on other foundation as shown on the plans rdered by the Engineer.

2. **Material.**—The blocks shall be from 6 to 9″ long and shall average ıey shall be 3″ in depth and from 3 to 4″ in width; but all blocks in one of pavement shall be of uniform width. No variation greater than 1/16″ ɔe allowed in the depth and 1/8″ in the width of the blocks.

3. Blocks shall be made from Southern yellow pine, North Carolina Norway pine, black gum or tamarack; only one kind of wood however be used in one piece of pavement.

Yellow pine block shall be made from what is known as Southern y pine, well manufactured, full size, saw butted, all square edges, and sha free from the following defects:

Unsound, loose and hollow knots, worm holes and knot holes, thr shakes and round shakes that show on the surface. In yellow pine ti the annular rings shall average not less than six to the inch and shall no case less than four to the inch, measured radially.

Norway pine, gum, North Carolina pine and tamarack block shall b from timber that is first-class in every respect, and shall be of the same as that defined for the Southern yellow pine.

59.4. The creosote oil with which the blocks shall be treated shall cor to either of the following specifications, designated as "A" and "B."

The preservative to be used under this specification shall be a produ coal gas, water gas or coke oven tar, which shall be free from adultera and contain no raw or unfiltered tars, petroleum compounds, or tar pro obtained from processes other than those stated.

Specification "A"

The specific gravity shall not be less than one and eight-hundredths (nor more than one and fourteen hundredths (1.14) at a temperature of t eight (38) degrees centigrade.

Not more than three and one-half (3½) per centum shall be insolub continuous hot extraction with benzol and chloroform.

On distillation, which shall be made exactly as described in Bulletin the Railway Engineering and Maintenance of Way Association, the d ate, based on water free oil, shall not exceed one-half (½) of one (1) pe tum at one hundred and fifty (150) degrees centigrade, and shall be no than thirty (30) nor more than forty (40) per centum at three hundre fifteen (315) degrees centigrade.

The oil shall contain not more than three (3) per centum of water.

Specification "B"

It shall be completely liquid at thirty-eight (38) degrees centigrade shall have a specific gravity at that temperature of not less than one and hundredths (1.03) nor more than one and eight hundredths (1.08).

It shall contain not more than two (2) per centum of matter insolu hot extraction with benzol and chloroform.

On distillation, which shall be made exactly as described in Bulletin of the American Railways Engineering and Maintenance of Way Associ the distillate based on water free oil shall be within the following l

At 210°C. not more than 5%.

At 235°C., not more than 35%.

At 315°C., not more than 85%.

The oil shall yield a coke residue not exceeding three (3) per cent.

The distillate, between 210°C. and 235°C., shall yield solids on cool 15°C. The preservative shall contain not more than 3% of water.

59.5. **Sampling of Oil.**—The manufacturer of the oil shall permit fu complete inspection and sampling at the factory at which the oil is proc of all materials either crude or refined, entering into the manufacture finished product itself, in order that the materials used can be deter to be in accordance with the foregoing requirements. He shall also s satisfactory proof of the origin of all materials entering into the compo of the finished product.

Samples of the preservative taken by the inspector from the treating during the progress of the work shall at no time show an accumulation of than 2% of foreign matter, such as sawdust or dirt.

59.6. The blocks shall be treated with the preservative above describ that they shall contain at least 16 lb. of the same per cubic foot of ti

The manufacturer of the block shall equip his plant with all nec gauges, appliances and facilities to enable the inspector to satisfy h that the requirements of the specifications are fulfilled.

59.7. **Method.**—Upon the foundation shall be spread a bed of cemen tar at no place less than ½″ in thickness, composed of one part Po cement and four parts sand thoroughly mixed dry. This morta shall be struck with a template to a true surface exactly parallel to th of the proposed pavement surface and 3″ below it. The bed sh sprinkled, immediately in advance of the block laying, with clean wa hand sprinklers.

3. On the mortar surface prepared as described, the blocks shall be laid grain vertical and at such angles with the curb as the Engineer may :. The block shall be laid in straight and parallel courses and set y together but the joints shall not exceed $\frac{1}{8}''$ and the blocks shall not iven together. Each course of blocks shall be of uniform width and ı, with end joints broken by a lap of not less than $2\frac{1}{2}''$. Only whole s shall be used except in starting courses, cutting closures, or where ılly permitted by the Engineer. Expansion joints of the same character specified for "Brick Pavements" shall be used as shown on the plans or lered by the Engineer. On steep grades or elsewhere as shown on the or as ordered by the Engineer, iron or steel plates shall be furnished, ed and secured in the transverse joints. Such plates shall conform ly to the surface of the paving. Payment for them will be made under "MISCELLANEOUS IRON AND STEEL."

›sures shall be carefully cut and trimmed by experienced men, the por- f the blocks used shall be free from defects and the cut end shall have a e perpendicular to the top of the block and cut at a proper angle to give e joint. In laying block the pavers must stand on the block previously

er the laying is completed, defective blocks shall be carefully culled out, locks raised, the courses carefully aligned and the blocks spaced up. avement shall then be rolled by a self-propelled tandem roller weighing ss than $2\frac{1}{2}$ tons nor more than 5 tons; the pavement being at the same lightly sprinkled and the rolling continued until a uniform surface is ned. Upon the completion of the rolling any defective blocks shall be ed and be replaced with sound blocks, and displaced blocks shall be ned. The joints in the pavement shall then be immediately filled in anner hereinafter described. If deemed advisable by the Engineer, ns of pavement laid with blocks which have become "dried out" shall rinkled with water at frequent intervals before joints of same are filled.

9 After rolling, the blocks shall be flushed with an approved bituminous heated to at least 300°F., which shall be poured over the whole surface ell forced into the joints by rubber squeegees. While the bituminous s still hot it shall be immediately followed with a thin coating of clean and. Before turning traffic onto the pavement a coating of $\frac{1}{2}''$ in ness of dry screened sand shall be spread over the entire surface.

10. **Measurement and Payment.**—The quantity to be paid for under tem shall be the number of square yards, including expansion joints, ement laid in accordance with the plans and as directed by the Engineer. e price bid shall cover the furnishing and placing of the mortar bed, pt PORTLAND CEMENT), wood block, bituminous filler and sand surfac- nd all other labor and incidental expenses necessary to complete the

ITEM 62—STONE BLOCK PAVEMENT.—TYPE 1
ITEM 62A—STONE BLOCK PAVEMENT.—TYPE 2

1. **Work.**—Under this item the Contractor shall furnish and place upon erly prepared foundation Stone Block pavement of the quality specified , as shown upon the plans or directed by the Engineer.

e item will include the furnishing and placing of all the block, sand n, grout, expansion joints and all material, labor and other expenses ntal thereto, but will not include the concrete foundation, edging, ıg, manholes, catch basins, etc., which will be paid for under the especi- esignated items therefor.

2. **Material.**—The dimensions of granite or other blocks except of a sandstone shall be as follows: Not less than 8″ nor more than 12″ n top, not less than $3\frac{1}{2}''$ nor more than $4\frac{1}{2}''$ wide on top, and not less $4\frac{3}{4}''$ nor more than $5\frac{1}{2}''$ deep. They shall be dressed so that after no measurement of any joint shall show a width of more than $\frac{1}{2}''$ for a of 1″, or a width of more than 1″ in any part of the joint. The head block shall be so cut that it shall not have a depression in it more than leep, and the edges and corners must be full unchipped and unbroken. ocks shall be sorted and laid in straight course of uniform width and

e dimensions of the Medina sandstone blocks shall be as follows: Not less 3″ nor more than 13″ long on top; not less than 3″ nor more than $5\frac{1}{2}''$ on top and not less than 6″ nor more than 7″ deep. They shall be d so that after laying no measurement of any joint shall show a width re than $\frac{1}{2}''$ for a depth of $2\frac{1}{2}''$ or a width of more than 1″ in any part

of the joint. The head of the block shall be so cut that it shall not h depression in it more than ⅜″ deep and the edges and corners must b unchipped and unbroken. All blocks shall be sorted and laid in str courses of uniform width and depth.

62.3. The blocks shall be of stone of medium sized grain showing an distribution of constituent material. They shall be of uniform qualit texture, without seams scales or disintegration. They shall be made rock which when tested in the Deval Rattler will show a "coefficient of v of more than 7 and less than 14. All blocks for any one contract sh from the same quarry unless otherwise directed.

62.4. **Method.**—On the prepared foundation, sufficient clean Cu Sand as described under "Materials of Construction" shall be spre such a thickness that after the pavement has been thoroughly ramm settled the sand under the block shall be nowhere less than 1″ thick.

Premoulded longitudinal expansion joints shall be placed along side curb or edging and shall conform strictly to the requirements given "Materials of Construction."

These joints must extend to the depth of the block. No transverse shall be allowed. The material should be made into strips of suitable l and of the required depth and thickness as shown on plans and should b in the pavement with the ends loosely joined as the block are being

On the sand cushion above specified the blocks shall be set vertical edge in close contact with each other, and in straight rows across the rc right angles to the curb, except at intersections or curves, where the an the rows with the curb shall be varied to meet the conditions. Blo adjoining rows shall be set to break joints not less than 3″. All blocks be set so that when thoroughly rolled or settled to a firm, unyielding be they will then be true to lines, grades and cross-sections, and have no greater than the maximum allowable. All depressions or irregularit the surface shall be corrected to the satisfaction of the Engineer. practiced and competent pavers shall be employed in laying the b

After the blocks are laid, sufficient approved clean gravel shall be s over the surface and swept into the joints so as to fill the latter to a de about 2″ from the bottom. The blocks shall then be thoroughly rolled firm, with a roller weighing not less than 6 tons, even and true to the grades and cross-sections. Blocks not brought to true surface by r shall be rammed.

Portland cement grout mixed in proportions of 1 part cement and 2 sand shall then be poured into the joints until the grout flushes to the s of the pavement. The grout shall be broomed when required, and the ing and brooming shall be continued until all the joints are thoroughly and the grout is even with the highest part of any and all blocks. I grouting the blocks shall be wet by sprinkling or otherwise. Grout sh mixed as specified under Item 61.

62.5. **Covering.**—After grouting shall have been completed and the shall have sufficiently hardened, a coating of suitable material about 1′ shall be spread over the whole surface of the grouted pavement, and the shall then be sprinkled with water. This covering shall be kept wet no travel of any kind shall be allowed on the completed pavement least 10 days thereafter, nor until the grout shall have thoroughly set, the covering shall be completely removed.

62.6. **Measurement and Payment.**—The quantity to be paid for unde item shall be the number of square yards of pavement within the edgi curbing laid in accordance with the plans and as directed by the Eng

The price bid shall cover the furnishing and placing of all materials, (e Portland Cement), the spreading of sand cushion, the laying, r grouting, surfacing and all labor and incidental expenses necessary to plete the work.

Item 62—A

The specifications for this item will be the same as those given under 62 and entitled "Stone Block Pavement, Type 1," except in the foll details:

Cement-sand Bed.—Not less than 10 days after the concrete found has been completed, there shall be spread upon this foundation a b cement and concrete masonry sand, consisting of 1 part cement and 4 of concrete masonry sand of which the depth shall not be greater th after rolling. The sand and cement must be thoroughly mixed dry l

cing either by an approved type of mixer, or by hand, on a mixing board pan. The materials shall be thoroughly mixed until a uniform color is ained and should be spread on the foundation in this condition. The ıent-sand bed shall be struck off with a template and be brought to the ct form and section shown on plans to the required depth below the shed grade. After the bed has been leveled off it shall be rolled with a d roller weighing about 300 lb. If any depressions develop they shall be d in and the bed again leveled and the rolling shall be repeated as many es as are necessary to compress the sand bed. Tramping upon the cement-d bed is prohibited. The inspector must keep the block culled and the ıtractor shall make the necessary changes and replacements so that the k at all times shall be ready for the grouting within 100 ft. of the block .

ll block laid must be rolled ready for grouting at the end of the working od and each day's work must be completed in full.

efore the grouting is applied the rolled block shall be thoroughly wet by nkling. It is important that the blocks be well wet so as to set up the ent-sand bed. An excess of water over that required and taken up by cement-sand cushion must not be used. The operation of grouting will ollowed as for "Type 1."

ayment will be made as for "Type 1" except that it will also cover the ent-sand bed (except PORTLAND CEMENT).

Item 56. Trimming Shoulders New York

Work.—Under this item the contractor shall form and trim shoulders, ıes, and slopes in a workman-like manner to the lines and grades of the cal sections shown on plans and as the engineer may direct. The ılders should be rolled with a roller weighing not less than 3 tons and ın a compact and satisfactory condition at the completion of the contract.

Measurement and Payment.—The quantity to be paid for shall be number of linear feet measured along the axis of the roadway where the k is actually performed.

he price bid per linear foot of road shall cover all labor and incidental k necessary to trim, form, and compact shoulders, ditches, and slopes ıe line and grade shown on the plans or as ordered by the engineer.

STANDARD SPECIFICATIONS FOR LOCAL IMPROVEMENTS

City of Rochester, N. Y.

Division E. Sidewalk Construction

(1920 Edition)

Table of Contents

E-1. Subgrade and Drainage

a. **Preparation of Subgrade.**—1. The ground to be occupied by the s walk shall be excavated or filled to a subgrade, which, after being compac shall be such a depth below the finished surface of the sidewalk as may shown on the plans. The subgrade shall immediately be dressed to a p surface containing no large stones, roots, sod, or rubbish and shall sl downward toward the street ½″ in 1′, horizontally, and to such long dinal grade as may be shown on the plans. The completed subgrade s project 4″ in excavation and 18″ in embankment on each side beyond edges of the completed walk. After the grading is completed, the sur shall be compacted by rolling or ramming. All soft and spongy pl shall be removed and all depressions filled with material as nearly as poss conforming to that in the remainder of the subgrade. All filling sha compacted in layers not exceeding 6″ in thickness.

2. Trees shall not be cut down or otherwise disturbed except by orde the engineer as shown on the plan. Any tree to be removed must be grub out or excavated with all of its principal roots and in case of cement w for the entire width of the sidewalk. Trees having a diameter of 6″ or (will be paid for, the measurement to be taken 3″ above the ground. I ment for the removal of such trees will be made in accordance with contract price for the removal of trees.

Stumps will be removed when encountered in the work. They mus grubbed out or excavated as in the case of trees. Stumps having a diam of 6″ or over at the place where they were cut will be paid for at the cont price bid for removing stumps.

3. Roots and trees which are not removed, but which are contiguous to line of the sidewalks, and in any manner interfere therewith, must be trim and cut away as the engineer shall direct. Where the engineer may dir the sidewalks shall be fitted to such trees.

b. **Surface Drainage.**—1. In establishing the grade for the walk, 1″ s be added to the grade resulting from the ½″ rise per foot from the c grade, so that the earth slope from the curb to the walk shall be left 1″ be the walk surface, to insure proper drainage of all water from the sidew The grade established will be the side nearest the curb.

c. **Provision of Underdrainage.**—1. When shown on the plans or requ by the engineer, a suitable drainage system shall be installed and conne with sewers or other drains as indicated.

2. On the subgrade prepared as specified, the drainage course, w required, shall be thoroughly rolled or tamped to a surface at least 5″ be the finished grade of the walk. The drainage course shall be compose broken stone, gravel, or boiler-plant cinders 4″ in thickness when compac The broken stone for this purpose may be any durable stone, crushe such size that all will pass through a screen with 2″ openings and be retai on a ¼″ screen. Gravel for the purpose may be any sound, durable gra all of which shall pass through a 2″ screen and be retained on a ¼″ scr If cinders are used they must be good boiler-plant cinders from which ashes have been screened out. The cinders must be thoroughly drenc with water before they are placed on the sidewalk.

. The bottom of the drainage course shall be connected with street ins, or sewer inlets, by 3″ hard farm tile drain pipe at such points, not e than 200′ apart, as will drain all the standing water out of the drainage rse.

. While compacting the subgrade and drainage course, the material shall cept thoroughly wet and shall be in that condition when the concrete is osited; unless the subgrade is composed of damp clay, in which case a care must be taken to prevent it becoming too soft.

Prices to Cover.—The cost of preparing the subgrade as specified above Subdivision *a*, except as otherwise provided, shall be included in the tract price for subgrade. Where underdrainage is required by the plans by order of the engineer, the cost of providing the materials and concting the drainage course complete, as specified above in Subdivision *b*, s. 1 to 4, inclusive, shall be included in the contract price for drain tile underdrainage.

Where contracts are for walks only, the items for extra earth excavation l include all excavation above the finished grade line, as shown on the dard plans, and shall be for such width as indicated by a special section.

E-2. Foundation and Wearing Surface

Forms, Dimensions, and Joints.—1. Forms shall be free from warp and e sufficient strength to resist springing out of shape. The forms shall be staked or otherwise held to the established lines and grades and their er edges shall conform to the established grade of the walk. All wood ns shall be thoroughly wetted and metal forms oiled before depositing material against them. All mortar and dirt shall be removed from forms have been previously used.

The slabs or independently divided blocks, when not reinforced, shall e an area of not more than 36 sq. ft. and shall not have any dimensions ter than 6′. The large slabs shall be reinforced as hereinafter specified. eneral, no walk shall be less than 5′ in width.

Each slab shall be separate from the adjoining one by a straight joint l with tar paper. All joints shall be made with a jointing tool not less ¼″ thick, and so made as to slightly round the corners of the flags.

The thickness of the walks shall be generally 1″ in thickness for each in width, but in no case less than 5″ for a two-course walk, or 4″ for a course walk, for residence streets, and not less than 6″ for a two-course on business streets. The maximum thickness will be shown on the s.

A ½″ thick expansion joint of asphaltic felt the same depth as the rete shall be provided at least once in every 50′. Wherever the walk nds directly against the curb or building, a ½″ expansion joint of altic felt shall be provided.

Unless protected by metal, the upper edges of the concrete shall be ded to a radius of ½″.

Where steel dividers are used between each slab, tar paper and asphaltic joints may be omitted.

Two-course Walks.—1. Where the sidewalk extends from the curb to ilding a two-course walk may be laid, otherwise a one-course walk shall id.

The foundation course of a two-course walk shall be composed of land cement concrete designated as Class *B* concrete in these specifica-s. The proportioning, mixing, and placing of concrete shall be done in rdance with the specifications for Class *B* Portland cement concrete. Division B-1 of these specifications.)

Slabs having an area of more than 36 sq. ft. or having any dimension ter than 6′ shall be reinforced with wire fabric or with plain or deformed . The cross-sectional area of metal shall amount to at least 0.041 sq. in. ineal foot. The reinforcement shall be placed upon and slightly pressed the concrete base immediately after the base is placed. Reinforcement not cross an expansion joint. Where joined it shall be lapped sufficiently evelop the full strength of the metal.

The wearing-surface course shall be mixed in the manner specified for ng Portland cement concrete (see Division B-1) and shall be composed of s *B* Portland cement mortar. Both the Portland cement and the fine egate used shall conform to the requirements of these specifications, sion B-1. The mortar shall be of a consistency that will not require ping, but which can easily be spread into position.

5. The wearing-surface course shall have a minimum thickness of 1″ shall be placed immediately after mixing. In no case shall more thai min. elapse between the time the concrete for base is mixed and the time wearing course is placed.

6. After the wearing course has been brought to the established grac shall be worked with a wooden float in a manner that will thoroughly c pact it. When required, the surface shall be troweled smooth, but exce working with a steel trowel shall be avoided. The slab marking shal made in the wearing course, directly over the joints in the base, with a which will completely separate the wearing courses of adjacent slabs.

7. If excessive moisture occurs on the surface, it must be taken up wi rag or mop, and in no case shall dry cement or a mixture of dry cement sand be used to absorb this moisture, or to hasten the hardening.

8. *Prices to Cover.*—The cost of furnishing and preparing the material constructing the foundations and wearing surface, as specified abov subdivisions *a* and *b*, shall be included in the contract price for founda and wearing surface of two-course sidewalks, except that where reinforcer is required additional payment shall be made, at the contract price reinforcement, for such quantities as are shown on the plans or require written order of the engineer.

c. **One-course Walks.**—The general requirements of the specificat covering two-course walks will apply to one-course walks with the follo exceptions:

1. The concrete shall be Class *A* concrete, as specified in these spec tions, Division B-1, Subdivision *d*.

2. In general, one-course walks shall be laid on all residential streets.

3. The thickness of one-course walks shall be not less than 4″ at section.

4. The forms shall be filled, the concrete struck off, coarse particles fc back from the surface, and the work finished as specified under two-cc walk, Subdivision *b*.

5. When a one-course walk is to be reinforced the metal shall be place from the finished surface. The minimum amount of metal shall be as s fied under two-course walk.

6. *Prices to Cover.*—The cost of furnishing and preparing the materia constructing the sidewalk, as specified above in Subdivisions *a* and *c*, be included with contract price for one-course sidewalks, except that v reinforcement is required additional payment shall be made, at the tract price for reinforcement, for such quantities as are required by wı order of the engineer, or shown on the plans.

d. **Protection of Walks.**—1. When completed, all walks shall be moist and covered with canvas or boards and protected from traffic an elements for at least 3 days, and shall not be opened to traffic until the neer so directs. The cost of such protection shall be included in the con price for sidewalk construction.

2. If, at any time during the progress of the work the temperature is, the opinion of the engineer will within 24 hrs. drop to 35°F., the wate aggregate used in preparing the concrete shall be heated, and precau shall be taken to protect the work from freezing for at least 5 days.] case shall concrete be deposited upon a frozen subgrade or subbase. concrete shall be laid in freezing weather.

Item 12.—Changing Elevation of Manholes and Catch Basins[1]

a. **Work.**—Under this item the contractor shall raise or lower, tc grades given, all existing covers of catch basins or manholes.

b. **Material.**—All changes shall be made with acceptable brick la Portland cement mortar of 1 part cement and 2 parts concrete sand.

c. **Method.**—All work shall be done in a workman-like manner by co tent masons.

d. **Measurement and Payment.**—For each manhole or catch basin r or lowered as directed by the engineer, the contractor shall receive the price bid.

The price bid shall cover all labor, materials (except Portland cem and incidentals necessary to complete the work. If any manhole or c. basin heads or covers are broken through carelessness on the part o contractor, they shall be replaced at his expense.

[1] New York.

Item 7. Pipe Underdrain[1]

. Work.—Under this item the contractor shall furnish and lay, at his on, porous tile, vitrified clay, or concrete pipe wherever required for nage, of the size indicated on the plans or in the itemized proposal.

Material.—1. Porous tile shall be whole and free from cracks and other cts and must be satisfactory to the engineer.

. Vitrified clay pipe shall be first-quality, double-strength, salt-glazed, ıd, vitrified, stoneware pipe.

Concrete pipe shall be first quality and free from cracks and other cts, and must be satisfactory to the engineer. The concrete shall con- of a mixture of 1 part Portland cement, 2 parts concrete sand, and 3 s of broken stone or screened gravel of No. 1 size.

Method.—The pipe shall be laid true to line and grade on a 2″ bed of 2 size stone, gravel, or slag and shall be covered as laid with broken stone, ened gravel, or broken slag, placed around and above it to a height and manner as directed by the engineer. The joints shall be wrapped with a of burlap or tar paper not less than 6″ wide and lapped at least 6″ on of the pipe.

Measurement and Payment.—The amount to be paid for under this ı shall be the number of linear feet of pipe furnished and incorporated in work.

he price bid shall cover all labor, materials, and incidentals necessary to plete the work, except that the necessary excavation will be paid for er the item Excavation, and the necessary broken stone, broken slag, or ened gravel will be paid for under the items Broken Stone, Loose surement, Broken Slag, Loose Measurement, or Screened Gravel, Loose surement.

Item 10. Relaying Old Pipe[1]

Work.—Under this item the contractor shall, as directed, carefully ove, preserve, haul, and relay old pipe found in existing culverts.

he old pipe when relaid shall be true to line and grade and have a full, , even bearing, and the work shall be in every way the same as if new were being laid.

xisting pipe in good condition which is damaged in removing, due to the lessness of the contractor, shall be replaced with new pipe at the con- tor's expense.

xisting pipe which is, in the engineer's judgment, unfit for relaying may estroyed before removing.

Measurement and Payment.—The amount to be paid for under this shall be the number of linear feet incorporated in the work. New pipe ished to replace old pipe which is destroyed through the carelessness of contractor shall be paid for as if the old pipe had been preserved and d.

e price bid shall cover the labor, materials, and incidentals necessary omplete the work, except that the excavation necessary will be paid for r the item Excavation.

Drop Inlets[1]

rop inlets shall be constructed where shown upon the plans, or directed ie engineer. The details of construction shall be such as he may direct.

ıyment for drop inlets will be made under appropriate items at the con- price for the materials entering into their construction; that is, payment be made for the various amounts of excavation, concrete, miscellaneous and steel, cast-iron pipe, Portland cement, etc. Payment under these s shall cover all labor and materials necessary to complete the work.

Item 15. Stone Filling[1]

Work.—Under this item the contractor shall furnish and place accept- stone or either quarry, field, or cobblestone on slopes, in fills, in crib , and similar work as required. The larger stones shall be properly edded at the bottom of the fill; all stones shall be so placed as to make a f maximum capacity.

Measurement and Payment.—The quantity to be paid for under this shall be the number of cubic yards measured in its final position and porated in the work as directed by the engineer. The price stipulated cover the cost of obtaining the stone, placing and all materials and ıses incidental thereto, except that the excavation necessary will be paid nder the item Excavation.

ew York.

Item 16. Rip-Rap[1]

a. **Work.**—Under this item the contractor shall furnish and place rip for slope protection where shown upon the plans or ordered by the engir

b. **Material.**—Rip-rap shall consist of field stone or rough, unhewn qu stones as nearly cubical in form as is practicable, placed upon a slope steeper than the angle of repose, and so laid that the weight of the l stones is carried by the soil and not by the stones adjacent. Fifty per of the mass shall be large stones of 2 cu. ft. or more.

The largest stones shall be placed first, roughly arranged and in contact; the stones shall rest upon a 6″ bed of stone chips or gravel or c acceptable porous material, where ordered by the engineer. The sp between the larger stones shall be filled with spalls of suitable size.

c. **Measurement and Payment.**—The quantity of rip-rap to be paic under this item shall be the number of cubic yards placed in accordance the plans or as directed by the engineer. When a porous bed is place accordance with the directions of the engineer, the quantity of the same be included in the quantity of rip-rap and paid for as such.

The price bid shall cover all labor, materials, and incidental expe necessary to complete the work satisfactorily, except that the excava necessary will be paid for under the item Excavation.

Item 18. Timber and Lumber[1]

a. **Work.**—Uuder this item the contractor shall furnish and plac timber and lumber of various sizes as may be ordered for sills or platf beneath the road, for culverts, bridges, reinforcing existing structures, for other similar purposes as ordered by the engineer.

b. **Material.**—Timber and lumber shall be of shortleaf yellow pin spruce or other acceptable kind, sound, square-edged, free from sh loose knots, or decay, and shall be planed and framed if required.

c. **Work Not Included.**—No payments will be made under this iten timber or lumber for forms, molds, or centers, for sheeting or bracing, folds, fences, guide rails, or any part of the contractor's temporary bri roads, or plant; but payment for timber and lumber used in the above shall be included under the appropriate items covering the same.

d. **Measurement and Payment.**—The quantity of timber and lumber paid for shall be the number of thousand feet, board measure, act placed in accordance with orders of the engineer. If any round timt used it shall be estimated as square timber of the largest size, omitting tions of an inch, which can be inscribed in the small end of the log.

No second-hand timber shall be used except with the approval ol engineer. The price bid shall cover all bolts, spikes, and other faster and all other material and expenses incidental of furnishing, framing, placing the timber and lumber satisfactorily.

Item 27. Concrete Curbing[1]

a. **Work.**—Under this item the contractor shall place concrete curbin the type shown on the plans, where shown on the plans or ordered by engineer.

b. **Material.**—The concrete shall consist of a mixture of 1 part Port cement, 2 parts of concrete sand, and 3 parts of broken stone or scre gravel measured separately, and shall be mixed in accordance with the ge requirements of 'Concrete Masonry.

The aggregates for concrete curbing shall meet the requirements g in the detailed specifications, Materials of Construction.

c. **Method and Forms.**—Curbing shall be molded in place in sec 6′ long and provision made at each joint for expansion of ⅛″.

All forms shall be set true to line and grade and held rigidly in posi They shall be either of metal or of acceptable planed and matched lun and of such construction that a smooth surface will be provided.

The forms shall be left in place until the concrete has set sufficient that, in the opinion of the engineer, they can be removed without in to the curbing. The curbing shall immediately upon the removal of forms be rubbed down to a smooth and uniform surface, but no plastering be allowed. For this work a competent and skilful finisher shall be emplc

The curbing shall be covered, immediately after finishing, with burla other material acceptable to the engineer, which shall be kept wet 1 period of 3 days.

[1] New York.

Protection.—The contractor shall protect the curbing and keep it in -class condition until the completion of the contract. Any curbing ch is damaged at any time previous to the final acceptance of the work l be removed and replaced with satisfactory curbing at the contractor's ense.

Measurement and Payment.—The quantity to be paid for under this shall be the number of linear feet placed in accordance with the plans e directions of the engineer.

he price bid for concrete curbing shall cover the furnishing and placing l concrete, tile, porous filling, forms, and all materials (except Portland ent), labor, and incidental expenses necessary to complete the work, pt that the excavation necessary will be paid for under the item avation.

Item 34. Wooden Guide Railing[1]

Work.—Under this item the contractor shall furnish and erect wooden e railing of the type indicated, where shown on the plans or ordered by engineer.

Material.—The posts shall be of seasoned white oak, cedar, locust, rack, or chestnut. Posts and rails shall be sound, clear, and cut from timber. The posts shall be round, at least 6″ in diameter at the smaller after the bark is removed. Posts shall be shaved to even surfaces free bark or skin. The lower part of the posts to a point 3′ from the top be dipped while dry in suitable bituminous material heated to a temture of 300°F., or shall be charred as directed. The posts if dipped be thoroughly dry before being set in the ground.

ils shall be of seasoned, planed spruce or yellow pine and be properly ed to the posts, all in a workman-like manner.

hite paint used under this item shall conform to the specifications under erials of Construction.

Painting.—The joints of the rails and posts shall be given one coat of e paint before being put together; the beveled tops of posts shall receive heavy coats of the same. The entire surface exposed above the ground receive three coats of white paint. No paint shall be applied in wet eezing weather.

Measurement and Payment.—The quantity of wooden guide railing paid for under this item shall be the number of linear feet completed ace.

e price bid shall cover the furnishing and erecting of all posts and rail, xcavation, painting, dipping, hardware, and all expenses and incidentals sary to complete the work.

Item 35. Cable Guide Railing[1]

Work.—Under this item the contractor shall furnish and erect guide g as shown on the standard structure sheet at such places as indicated e plan or as otherwise directed by the engineer.

etches of guide railing more than 500′ in length shall have two interate anchors for each 500′ stretch or fraction thereof.

Material.—The posts shall be made of concrete consisting of 1 part of and cement, 2 parts of concrete sand, and 3 parts of crushed stone or ned gravel, all measured loose bulk in boxes or forms of known capacity. posts shall be reinforced as shown on the standard structure sheet with ated steel bars meeting all the requirements of the Standard Specificaof the A.S.T.M. Serial Designation A-15-14 or, at the contractor's n, with steel fabric meeting all requirements of the Standard Specificaof the A.S.T.M. Serial Designation A-82-21T.

exposed surfaces shall be finished true to line. No plastering of any e will be permitted.

er erection, all exposed surfaces of the post shall receive a uniform ation of a solution consisting of 8 lb. of zinc sulphate to 1 gal. of water. pplication shall be permitted to set for at least 48 hr., after which the when perfectly dry, shall receive two coats of white paint meeting the ements under Materials of Construction.

ble shall be three-strand, seven-wire-to-the-strand, double-galvanized wire cable of ¾″ diameter. Individual wires shall be not less than ″ diameter.

e minimum tensile strength of the rope shall be 15,000 lb.

[1] ew York.

Each wire of the cable and all fittings and fastenings, except thre portions, shall be galvanized by the hot-dip method and shall have a tinuous coating of pure zinc of a uniform thickness, so applied that it adhere firmly to the surface of the wire, and it shall be capable of withst ing four immersions in a standard testing solution of copper sulphate wit showing any trace of metallic copper on the steel. The first three immer shall be for a period of 1 min. each and the fourth immersion for a peri ½ min.

The threaded portions of all fittings and fastenings shall have a con ous coating of pure zinc of a uniform thickness, so applied that it will a firmly to the surface of the thread, and it shall be capable of withstandin immersions, of 1 min. each, in a standard testing solution of copper sul without showing any trace of metallic copper on the steel.

These threaded portions shall receive, after erection, two coats of a num paint meeting the requirements under Materials of Construction.

c. **Measurement and Payment.**—The quantity of guide railing to be for under this item shall be the number of linear feet outside to outsi posts, completed in place, as shown on the plans or as directed by the engi

The price bid shall cover the furnishing and placing of all mat the excavation, backfilling, and all other labor and incidental expenses r sary to complete the work satisfactorily.

Item 36. Concrete Guide Posts[1]

a. **Work and Material.**—Under this item the contractor shall furnis erect concrete posts conforming to the requirements of Item 35.

After erecting, all exposed surfaces of the posts shall receive a un application of a solution consisting of 8 lb. of zinc sulphate to 1 gal. of v This application shall be permitted to set for at least 48 hr., after whic posts, when perfectly dry, shall receive two coats of white paint, meetir requirements under Materials of Construction.

These posts shall be erected and spread as directed by the engineer.

b. **Measurement and Payment.**—The number of concrete guide to be paid for under this item shall be the number erected in accordance the plans and orders of the engineer.

The price bid shall cover furnishing and placing of all materia excavation, backfilling, and all labor and incidental expenses necessa complete the work satisfactorily.

Item 57. Removing Old Bituminous Carpet[1]

a. **Work.**—Under this item the contractor shall remove the old bitum carpet as shown on the plans or as directed by the engineer.

b. The loosened bituminous material shall be immediately removed the payment and deposited as directed by the engineer.

c. **Measurement and Payment.**—The quantity to be paid for unde item shall be the number of square yards of bituminous carpet remo accordance with the plans or as directed by the engineer.

d. The price bid shall cover all labor, appliances, and incidental ex necessary thereto.

Item 58M. Cleaning Existing Pavement (Per Mile); Item 58Y. Cle Existing Pavement (Per Mile) [1]

a. **Work.**—The purpose of the work called for under this item is to p the existing pavement for the application of a new top course or a w carpet.

b. **Method.**—Under this item the contractor shall clean the existing ment by the use of hand brooms or by the use of mechanical sweep approved type, as directed by the engineer, so as to uncover but not di the embedded stones of the pavement.

All mud, dust, and other dirt so swept off shall then be remove deposited in such places and in such manner as the engineer may dire

c. **Ruts.**—Ruts and depressions of a greater depth than 1″ belo general surface of the pavement shall be swept out by hand brooms u loose material has been removed and the embedded stones are uncove

The operation of cleaning out the ruts and depressions and filling with thoroughly compacted stone or slag and binder to the general le the surface shall immediately follow the general operation of cleanir surface.

[1] New York.

. **Measurement and Payment.**—The price bid shall include all labor, ls, appliances, the removal of material cleaned from the surface, and all er expenses incidental thereto.

'he amount to be paid for under this item shall be the actual quantity of sting pavement, cleaned in accordance with the above and to the satis-ion of the engineer.

Item 59. Scarifying and Reshaping Old Macadam[1]

. **Purpose.**—The purpose of the work under this item is to prepare old adam pavement for the application of a top course.

. **Work.**—Under this item the contractor shall thoroughly scarify the macadam, by hand picking or by means of a mechanical scarifier of roved type. When a roller with spiked wheels is used the macadam must urther broken by hand picking, or plowing and harrowing.

'he loosened stones shall then be forked or raked over as directed by the ineer, after which the macadam shall be compacted by rolling with a -propelled roller weighing not less than 10 tons until an even and firm ace is produced, after which coarse gravel or screenings shall be used to all voids. If necessary in order to compact the stones satisfactorily, the adam shall be sprinkled during the process of rolling and filling.

Measurement and Payment.—The quantity to be paid for under this n shall be the actual number of square yards scarified, reshaped, rolled, led, and compacted to the satisfaction of the engineer, and the price bid l cover the furnishing of the necessary filler and all labor, appliances, expenses incidental thereto.

Item 34—Guide Signs

4.1. Under this item the Contractor shall furnish and erect guide signs he type indicated where shown upon the plans or ordered by the Engineer.

4.2. Permanent guide signs shall be for the purpose of furnishing perma-t directions to traffic after the completion of the contract. Permanent le signs shall be constructed of kiln dried white pine and of the dimensions wn on the plans. They shall first be given four coats of white lead mixed n linseed oil. After the last coat has become thoroughly dried the letters l be painted with black enamel paint, and when this is thoroughly they shall be given one coat of the finest white shellac.

4.3. Temporary guide signs shall be for the purpose of guiding traffic ig a detour during construction. Temporary guide signs shall be structed of kiln dried white pine and of the dimensions shown on the is. They shall first be given three coats of white lead mixed with linseed After the last coat has become thoroughly dried the letters shall be ited with black enamel paint.

4.4. The number of guide signs to be paid for under this item shall be number of signs placed in accordance with the plans and ordered by the ineer. All signs become the property of the State upon payment for this ı.

he price bid shall include the furnishing of all labor and materials neces- to satisfactorily erect permanent guide signs on sign posts and temporary e signs including sign posts, each guide sign complete in place.

Item 35—Highway Number Signs

.1. Under this item the Contractor shall paint on the concrete sign highway number signs of the type indicated where shown upon the s or ordered by the Engineer.

.2. Highway number signs shall be painted on all concrete sign posts letters which shall first be formed of two coats of flat black mixed in oil afterward retraced with black enamel.

.3. The number of highway number signs to be paid for under this shall be the number placed in accordance with the plans and ordered ie Engineer.

ie price bid shall include the furnishing of all labor and materials to factorily complete the work.

[1] New York.

Item 36—Danger Signs

36.1. Under this item the Contractor shall furnish and erect da signs where shown upon the plans or ordered by the Engineer. T shall be of the type called for by the plans.

36.2. Danger signs shall be constructed of a material and pai similar to that specified for guide signs and shall be of the dimensions lettered as shown on the standard plans. These signs shall be placec the standard concrete sign posts and set at an angle of forty-five deg to the center line. When the standard sign is used the arrow shall poi the direction of the danger.

36.3. The number of completed danger signs for which the Contra will receive payment will be the number placed in accordance with the p and ordered by the Engineer.

The price bid shall include the furnishing of all labor and materials n sary to complete each danger sign in a satisfactory manner.

Item 37—Concrete Sign Posts

37.1. Under this item the Contractor shall furnish and erect con sign posts of the type indicated, where shown upon the plans or ordere the Engineer.

37.2. Concrete sign posts shall be made of first-class concrete and o dimensions and materials shown on the standard plans. To these shall be securely fastened guide boards and signs.

37.3. The number of completed concrete sign posts to be paid for u this item shall be the number erected in accordance with the plans ordered by the Engineer.

The price bid shall include all concrete, reinforcement, forms, excav and backfill, and the furnishing of all other labor and materials nece to complete each concrete sign post in a satisfactory manner.

LOOSE STONE

Item 38—Screened Gravel—Loose Measure

Item 39—Broken Stone—Loose Measure

38.1. Under these items the Contractor shall furnish and place the road, as directed by the Engineer, broken stone and gravel of the designated on the Itemized Proposal. This stone and gravel will be for general repair work and for miscellaneous work.

38.2. The stone or gravel delivered shall be of approved quality and conform to the general requirements for broken stone and gravel, and shall be of the sizes ordered.

38.3. The quantity to be paid for under Items 38 and 39 respect shall be the quantity of broken stone or gravel furnished and delivered o work at the places and in the condition specified by the Engineer. V the material is produced by the contractor on the work, it shall be meas in cubic yards; it shall be measured in tons of 2000 lbs. when the mater imported and the weight is obtainable from reliable sources such as cer quarry or railroad figures.

The price bid shall include furnishing and delivering the stone or g as directed by the Engineer and all labor, appliances and expenses incid thereto; also the spreading, rolling or incorporating of the stone or g in the work, when required by the Engineer.

BRIDGES AND CULVERTS

Item 83. Timber Structures

83.1. **Description.**—All timber structures shall be built as indicated o plans, conforming to line, grade, dimensions, and design shown and in ac ance with the specifications for piling, concrete, untreated timber, tr timber, and other pay items which are to constitute the complete struc

83.2. **Material.**—(1) All timber shall be sound, sawed standard straight, out of wind, and shall be free from defects, such as decay, v holes, injurious shakes, checks, and crooked, cross, or spiral grain, l loose, or unsound knots, knots in groups, large pitch pockets, or other de

t might impair its strength and durability. Unless otherwise specified, ne may show on only one corner of a piece. Wane shall not exceed one- f the length of the piece nor measure more than 1″ across the face of the ne. Not more than 10% of the pieces of one size may show any wane.

3.3. (2) Standard size and dressing. Rough timbers sawed to "standard " shall be interpreted to mean that sawn rough timber shall not be over ′ scant from actual size specified. For instance, a 12 by 12″ timber shall asure not less than 11¾ by 11¾″. "Standard dressing" shall be inter- ted to mean that not more than ¼″ shall be allowed for dressing each face. For instance, a standard 12 by 12″ timber, dressed four sides, shall asure not less than 11½ by 11½″.

3.4. (3) All timber shall be classified as "dense," or "sound," and as eated" or "untreated."

3.5. (4) "Sound timber" shall meet all the requirements set forth above may be used for columns, sills, wheel guards, bulkhead sheeting, and cing.

3.6. (5) "Dense timber" shall be required for truss members, floor ms, stringers, caps, and flooring. Dense timber shall meet all the require- its set forth above and shall be classified as follows: (*a*) Dense timber of gleaf pine, shortleaf pine, and Cuban pine; (*b*) dense timber of coast region iglas fir; and (*c*) dense timber of other species.

3.7. *a*. Dense timber of longleaf pine, shortleaf pine and Cuban pine shall w at one end or the other an average of at least six annual rings per inch at least one-third summerwood, all measured over the third, fourth, and i inches on a radial line from the pith. Wide-ringed material excluded this rule shall be acceptable, provided the amount of summerwood as ve measured shall be at least one-half. The contrast in color between merwood and springwood shall be sharp, and the summerwood shall be k in color except in pieces having more than one-half summerwood.

3.8. In cases where timbers do not contain pith and it is impossible to te it with any degree of accuracy, the above inspection shall be made 3″ in an approximate radial line beginning at the edge nearest the pith mbers over 3″ in thickness, and in the second inch of the piece nearest to pith in timbers 3″ or less in thickness.

3.9. In dimension material containing the pith but not a 5″ radial line, ch is less than 2 by 8″ in section, or less than 8″ in width, that does not v over 16 sq. in. on the cross-section, the inspection shall apply to the nd inch from the pith. In larger material that does not show a 5″ radial the inspection shall apply to the third inch farthest from pith.

3.10. *b*. Dense timber of coast region Douglas fir shall be strong timber of ium rate of growth and show on one end or the other an average of at least nnual rings per inch, and at least one-third summerwood measured over n a line located as hereinafter described. Wide-ringed material, excluded his rule, shall be acceptable, provided the amount of summerwood as ve measured shall be at least one-half. Material in which the proportion immerwood is not clearly discernible shall not be used.

3.11. When the least dimension is 5″ or more, the pith being present, the over which the rate of growth and percentage of summerwood measure- ts shall be made shall run from the pith to the corner farthest from the . The 3″ line shall begin at a distance from the pith equal to 2″ less one-half the least dimensions of the piece.

.12. For all pieces not having the pith present, the center of the 3″ line be at the center of the end of the piece, and the direction of the 3″ line be at right angles to the annual rings.

.13. If a radial line of 3″ cannot be obtained, the measurement shall be e over the entire radial line that is available.

.14. *c*. Dense timber of other species. Other species of timber for truss bers, floor beams, caps, and flooring shall be strictly first quality.

.15. (6) **Untreated Timber.**—For designs based on a fiber stress in ing of 1500 to 1600 lb. per square inch, one of the following species of er shall be used:

Douglas fir from Pacific coast region.
Longleaf pine.
Cuban pine.
White oak.

.16. **Heart Requirement.**—All untreated timber shall show at least heartwood on any girth.

83.17. (7) **Treated Timber.**—Timber treated by a pressure method retain 8 to 12 lb. of oil per cubic foot, as hereinafter specified, and so trea that all sapwood is entirely impregnated with creosote oil, shall fulfil requirements for untreated timber except that there shall be no heartw requirement.

83.18. For designs based on a fiber stress in bending of 1500 to 1600 per square inch, one of the following species of timber shall be used:

Douglas fir from Pacific coast region.
Longleaf pine.
Cuban pine.
Shortleaf pine.
White oak.

83.19. **Preservation Treatment.**—Timber to be treated for preserva shall be cut and framed prior to treatment. After treatment no unneces cutting of treated piles or timber will be allowed.

83.20. The range of pressure, temperature, and time duration shal controlled so as to result in maximum penetration by the quantity of pre vative injected, which shall permeate all of the sapwood and as much of heartwood as practicable.

83.21. The amount of preservative and manner of treatment shall b indicated on the plans and shall fulfil the following requirements:

Timber shall be treated with the preservative specified by any stan full-cell process to retain not less than 12 lb. of the preservative per cubic or by any standard empty-cell process to retain not less than 8 lb. of preservative per cubic foot, except Douglas fir, which shall be treate retain not less than 10 lb. by any standard full-cell process or 6 lb by standard empty-cell process.

83.22. The preservative shall be one of the following grades of creo oil or creosote coal-tar solution as directed by the engineer, or indicate the plans, and shall meet the following requirements:

	Creosote oil Grade 1	Creosote oil Grade 2	Creosote oil Grade 3	Creos coal-t soluti
It shall not contain water in excess of	3 %	3 %	3 %	
It shall not contain matter insoluble in benzol in excess of	0.5 %	0.5 %	0.5 %	
Specific gravity of oil at 38/15.5°C. shall not be less than	1.03	1.03	1.03	1.05-1
The distillate based on water-free oil shall be within the following limits up to 210°C., not more than	5 %	8 %	10 %	
Up to 235°C., not more than	25 %	35 %	40 %	[illegible]
The float test of residue above 355°C. shall not exceed 50 sec. at 70°C. if the distillation residue above 355° exceeds	5 %	5 %	5 %	[illegible]
Coke residue of oil not more than	2 %	2 %	2 %	

The foregoing tests shall be made in accordance with Standard Metho A.S.T.M. Designation D38–18.

83.23. **Method of Construction.**—Treated timber shall be care handled without sudden dropping, breaking of outer fibers, bruisin penetrating the surface with tools. It shall be handled with rope sl Cant dogs, hooks, or pike poles shall not be used.

83.24. All places where the surface of treated timber is broken by cut boring, or otherwise shall be thoroughly coated with hot creosote oil then with a coating of hot tar pitch.

83.25. Pile caps shall be level and have full even bearing on all pil the bent and be secured to each pile a ¾″ diameter drift bolt extendi least 9″ into the pile.

3.26. Truss and bent timbers shall be accurately cut, and framed to a e fit in such manner that they will have even bearing over the entire con- ; surface of the joint. No blocking or shimming of any kind will be wed in making joints, nor will open joints be accepted. Mortises shall rue to size for their full depth and tenons shall make snug fit therein.

3.27. All bolt holes shall be bored with an augur 1/16″ smaller in diameter n the bolt. Mortises and tenons shall be "draw bored."

3.28. Stringers shall be sized at bearings. Outside stringers may have t joints but interior stringers shall be framed to bear over the full th of floor beam or cap at each end. The ends shall be separated at t ½″ for the circulation of air and shall be securely fastened to the timber which they rest.

'here width of stringers is less than one-third of the depth, then two lines by 4 bracing placed at quarter points of span shall be used.

3.29. Roadway floor plank shall have a nominal thickness of either 4 ″ as specified, and an actual width of not less than 9½″. Sidewalk floor ık shall be surfaced to uniform thickness. It shall have an actual mini- n width of 5½″ and thickness of 1⅝″.

3.30. All floor plank shall be laid heart side down with ¼″ openings and piked to each stringer or nailing strip with at least two 7″ spikes for 4″ k and two 6″ spikes for 3″ plank. Rough plank shall be carefully led as to thickness before laying, and be laid so that no two adjacent ks vary in thickness more than 1/16″. All floors shall be cut to a straight along the sides of the roadway and walkway.

3.31. Wheel guards, as shown on the plans, shall be constructed on each of the road. They shall be raised from the floor by blocks 3″ thick by ng, spaced about 5′ apart, center to center, and shall be fastened in place ⅝″ bolt passing through the wheel guard, each block and floor plank.

3.32. Railings shall be built in accordance with the designs shown on plans, and shall be constructed in a workman-like and substantial manner. ess otherwise noted, all railing material shall be dressed on four sides.

3.33. Pins may be turned, or split and drawn, from clear sound wood of kind specified on the plans. They shall be made 6″ longer than the ired finished length, and when driven into place shall have their ends ed off flush with the surface of the member.

3.34. Turned pins shall be made from square stock sawed parallel to the n. One end shall be left square for about 1″ and the other shall have a point. The body of the pin shall be uniform in diameter and 1/16″ larger the diameter of the hole. The finished pins shall be free from knots, holes, pockets, splits, or flaws which might impair their strength.

3.35. Split and drawn pins shall be made from straight-grained green ber and be allowed to season. One end shall be hardened and pointed by ring. They shall be octagonal in shape, and when seasoned, the neter between parallel faces shall be the same as the diameter of the s in which they are to be driven.

3.36. Bolts shall be of the sizes specified and must be perfect in every ect. They shall have square heads and nuts, and screw threads shall e close fits in the nuts. All bolts shall be effectually checked after the are adjusted.

3.37. Washers shall be used between all bolt heads and nuts, and the d. Cast washers shall have a thickness equal to the diameter of the bolt a diameter of four times the thickness. For plate washers, the size of square shall be equal to four times, and the thickness equal to one-half diameter of the bolt.

3.38. **Painting Treated Timbers.**—Hot creosote oil shall be poured into bolt hole before the insertion of the bolts, in such a manner that the e surface of the holes shall receive a coating of the oil. After the ssary cutting has been done to receive the cap, the heads of piles shall iven three coats of hot creosote oil. They shall then be covered with a of hot tar pitch over which shall be placed a sheet of three-ply ng felt or galvanized iron, or a covering may be built up of alternate rs of hot tar pitch and loose woven fabric similar to membrane water- fing, using four layers of pitch and three of the fabric. The cover shall sure at least 6″ more in each dimension than the diameter of the pile, and be bent down over the pile and the edges fastened with large-headed , or secured by binding with galvanized wire. After the cover is ace the cap shall be placed and drift bolted as prescribed above.

3.39. **Painting Untreated Timbers.**—In structures of untreated timber following surfaces shall be thoroughly coated with a thick coat of

red lead paint, hot tar, hot asphaltum, or hot coal-tar creosote be assembling: Heads of piles, end, tops, and all contact surfaces of caps, floor beams, and stringer ends, joints and all contact surfaces of t members, laterals, and braces. The back face of bulkheads and all o timber in contact with earth shall be thoroughly coated with one of materials specified above, or a carbolineum.

83.40. Unless otherwise specified, railings shall be made of untre dressed lumber and shall be painted with three coats of paint compose 75 % pure lead and 25 % zinc white by weight, mixed in pure, raw linseed Turpentine drier shall be added to the paint in the average proportion ½ pt. of dryer to 1 gal. of paint.

83.41. All bolts passing through non-resinous wood shall be painted two coats of red lead paint at least 85 % pure.

83.42. **Design Details.**—Features of loading are prescribed under de details for steel structures. Unit stresses shall be as shown on plans.

83.43. **Method of Measurement.**—"Treated timber" and "untre timber" complete in place according to the plans and these specificat shall be measured separately by the thousand feet board measure. Meas ments shall be computed from the dimensions shown on plans, unless cha in such dimensions have been authorized by the engineer. "Standa timber sizes shall be used in computations. This measurement shall inc only such timber as is a part of the completed and accepted w and shall not include timber used for erection purposes, such as falsew forms, bracing, sheeting, etc. Any piling, concrete, masonry, or supplementary floor wearing tops shown on plans will be measurec provided in pertinent specifications.

83.44. **Basis of Payment.**—Timber structures complete in place shal paid for by the quantities as above measured at the contract unit price thousand feet board measure bid for "untreated bridge timber" or "tre bridge timber," as the case may be, complete in place according to the p or as directed by the engineer, which prices shall be full compensation fo materials, hardware, equipment, tools, labor, painting, preservative tı ment, and all incidentals necessary to complete the structure ready for provided, however, that piling, concrete, masonry, and supplementary wearing tops shown on plans shall be paid for as provided in perti specifications.

MAINE STATE HIGHWAY COMMISSION, BRIDGE DIVISION

Soils

1. **Soils.**—*a.* The soils constituting the foundation materials upon w bridge abutments, piers, retaining walls, etc., are commonly placed are the purpose of these specifications, divided as follows:

1. Solid rock.
2. Loose rock.
3. Earth.

2. **Solid Rock.**—*a.* All hard-rock material existing in generally masses, which from the nature of its structure cannot be removed fron location without being drilled and blasted or otherwise broken into f ments, shall constitute solid rock.

3. **Loose Rock.**—*a.* All rock material existing in generally broken f ments by reason of having been separated by natural means into fragm which are removable from their locations by the use of pickaxs and c bars shall constitute loose rock. The drilling and blasting of loose roc facilitate its removal shall not be construed as giving to it the classifica of solid rock.

4. **Earth.**—*a.* All soil material other than solid and loose rock occur within the body of material to be removed from excavations for abutme piers, retaining walls, etc. shall be classified as "earth." This classifica shall include soils intermixed with boulders, loose and cemented sands gravels, hardpan, clay, gumbo, muck, etc. It shall also include wood w has become embedded within the soil by natural processes of time.

b. Whenever boulders are encountered within the excavations havin each boulder a volume of 1 cu. yd. or more, the contract unit price for lo rock excavation shall apply.

5. **Leveling Ledge Rock.**—*a.* Ledge rock, whether exposed by natur within excavated areas shall be leveled to secure satisfactory founda conditions for either concrete or stone masonry, as the engineer may di

ᵉ preparation of ledge rock surfaces to receive stone masonry shall be h as to secure a uniform, even bedding of the imposed stones. "Stilting" tones will not be permitted. In all cases the leveling shall be such as to ler the substructure secure against sliding. Surfaces worn smooth by ial, water, or other action shall be roughened and if rounded or tilted at angle with the horizontal shall be leveled horizontally as a whole or in s. All "shelly" areas shall be removed and cracks and fissures through ch water flows shall be calked or otherwise satisfactorily treated to remove flowing water from the foundation area. All ledge areas shall be thorhly cleaned to secure a proper bond with the stone or the concrete onry placed upon them.

Bridge Excavation

. **Excavation.**—*a*. Foundation pits and trenches shall, in general, be avated to the depths shown upon the plans and to such additional depths he engineer may direct in order to secure firm, practically incompressible dations having satisfactory safe load resistance, and to a satisfactory th below possible frost action. All pits and trenches in which piles are e driven shall be completed before driving is commenced, and following ompletion, all loose soil and chips, bark or other foreign material shall removed from the excavations before concrete or other substructure erial is placed therein.

The contractor shall be prepared to sheet the sides of excavations, and ut in proper walings, struts, shorings, and braces to protect the same caving.

To provide a working space for the construction of forms for concrete or the laying and pointing of stone masonry an allowance will be made naterial excavated outside of the base dimensions shown upon the plans, he basis of actual material removed, provided, however, that the maxin allowance outside of the base dimensions of abutments, piers, columns, shall not be greater than the following:

For concrete work.................................. 1′ 6″
For stone masonry work........................... 2′ 6″

allowance shall be made on account of slope of sides of excavations.

In the removal of the approach embankment of an existing bridge cture or of a previous structure the foregoing conditions governing vations shall apply. Unless otherwise provided in the contract, the h of an approach embankment shall be considered as the distance sured from its top surface vertically downward to the top of the original nd surface which existed prior to the construction of the embankment e latter can be determined by the existence of vegetable mold or other factory evidence. In the absence of satisfactory evidence the probable inal ground surface shall be assumed from such evidence as the engineer consider reliable and satisfactory.

Excavated Material.—*a*. All soil material taken from existing approach ankments and excavations except such as is acceptable and is required used for backfill around abutments, piers, retaining walls, etc., for the g of approaches, and for construction of embankments, shall be disposed the engineer may direct. Excavated material shall not be disposed of at tions obstructing the stream flow or otherwise impairing the efficiency or appearance of the bridge structure.

Excavated material accepted and used in backfill, in the filling of oaches, and in the construction of embankments shall be paid for as vation only when the entire work is performed at one and the same time.

Excavated material acceptable for use in the construction of embankts, in backfill, and in the filling of approaches, permissible, under the litions involved, of being placed therein without intermediate storage rehandling but used by the contractor in the construction of cofferdams, ection embankments, or other temporary structures incident to the ormance and completion of any part of the work shall be regarded as fill erial and shall be replaced at his own expense. Furthermore, such erial when wasted by reason of the methods and operations adopted by contractor in the excavation of the work shall likewise be replaced at xpense.

Unwatering.—*a*. The contractor shall at his own expense do all atering required in connection with the excavation of pits and trenches. ping shall not be permitted from the inside of forms for abutments,

piers, retaining walls, etc., while concrete is being placed therein. Su may be used within the space between cofferdams and the form w provided moving water is not permitted to come into contact with fr concrete or concrete that has attained only a "green" set.

9. **Approval of Foundation.**—*a.* Especial care shall be taken not to lo or disturb the soil forming the bottom of an excavation and the final rem of material just above the finished foundation elevation shall not be m until immediately before the construction of the substructure is commen Foundation excavations shall be examined and approved by the enginee

10. **Removal of Cofferdams.**—*a.* All cofferdams, dams, protec embankments, etc. used as a means for making excavations shall be remo unless otherwise provided, leaving the stream bed clear of obstruction th by. Stream bed or other areas excavated or eroded, incident to or resul from such temporary excavation protections shall be carefully backfi to the satisfaction of the engineer.

11. **Measurement of Excavation.**—*a.* All volumes of excavated mat shall, unless otherwise provided, be measured in the excavation. Howe volumes below the depths provided in the contract shall be subject to spe adjustment, in as far as payment therefor is concerned.

b. Clearing and grubbing and the removing of existing obstructions f the area to be excavated will be considered as included in the contract p for excavation.

Fill

12. **Backfill, Fill, and Embankment.**—*a.* All materials used for bac around abutments, piers, etc.; for fill in the rear of abutments; and for struction of approach embankments, protection embankments, etc., sha of a quality acceptable to the engineer as such. When the material cont insufficient moisture to permit thorough compacting, additional water this purpose shall be added. Material excavated from foundation pits trenches shall be used for these works, unless otherwise provided in contract or directed by the engineer. However, all material so used s be paid for as "Excavation" except in cases where the excavation an work are not executed simultaneously.

b. Material excavated from foundation pits and trenches and stored near the bridge site will, when rehandled and deposited in fill or embankr work, be paid for at the contract unit price or prices per cubic yard for "] but will not be again paid for as "Excavation."

c. Material taken from the adjacent roadway for use in the construc of fill or embankment will be paid for at the contract unit price or p per cubic yard for "Fill" but will not be paid for as "Excavation." W ever considered practicable by the engineer, improvements in the road alignment and grade shall be secured by this means. However, improvements shall not involve a maximum haul of the material, greater two thousand feet (2000′ 0″) nor shall they include the removal of ei loose or solid ledge rock except when specially provided in the contract a subsequent agreement.

d. All spaces excavated and not occupied by abutments, piers, or c permanent work shall be refilled with earth up to the surface of the surro ing ground or to such height as the engineer may direct. All backfill be thoroughly compacted and, in general, its top surfaces shall be ne graded.

e. Fill material used in the rear of simple span and arch abutments be deposited in successive layers not exceeding 12″ in thickness exten the full width of the cross-section and shall wherever possible, excep freezing weather, be compacted by thoroughly saturating or flooding water. In all cases where fill cannot be compacted by the use of wate shall be rammed or otherwise compacted as the engineer may direct.

f. Fill placed adjacent to culvert and other small structures shal deposited on both sides at the same time and to the same elevation.

g. Fill shall not be deposited against "green" set concrete; nor wedge-shaped sections of earth be placed against abutments, wing w arch spandrels, and retaining walls.

h. Approach embankments shall consist of filling the approache bridges, over arches, and around the ends of abutment wing walls to el tions above the surface of the surrounding natural ground area.

i. Protection embankments shall consist of earth embankments, usu rip-rapped, constructed to secure protection for bridge approaches, str diversions, etc.

Embankment material shall be deposited in successive layers not ›eding 12″ in thickness extending the full width of the cross-section, and ›pt in unimportant locations each layer shall be thoroughly compacted ›olling, ramming, or other satisfactory means.

When embankment material is to be deposited upon a hillside, the ace of the hillside area shall be cut into steps, ploughed, or otherwise sfactorily prepared to secure a bond with the new material to be imposed n it.

Material placed behind and over arches shall be deposited in layers as ›ribed for embankment work and will be deposited symmetrically from the nches upward until the crown is covered.

. Material subject to free erosion, such as loose sand, shall not be ›sited upon embankment slopes.

The sides of embankments shall, unless otherwise provided by the ›ract plans or required by the engineer, be graded to uniform even slopes ing a batter of one and one-half horizontal to one vertical (1½: 1).

The sides of all embankments unless protected by rip-rap, brush mat-s, or other approved means against stream scour or other erosive action l be seeded to produce a future grass sod protection. The kinds of grass to be used shall be approved by the engineer. However, the following ture of seed will be used unless otherwise provided:

; lb. timothy.
ı lb. red top.
3 lb. clover.
› lb. Japanese millet.

he seeding of slopes shall be done at periods of the year generally recog-d as satisfactory for the development of the sod protection. Whenever ›ssary, in the opinion of the engineer, the development of the seeding l be protected by a "cover crop" of oats, buckwheat, or other cereal.

The contractor shall be responsible for the stability of all constructed ›ankments and shall, until the work is finally accepted, replace any por-s which, in the opinion of the engineer, have become displaced as a result nproper workmanship, carelessness, or neglect on his part; or of damage lting from storms, cloudbursts, or other natural causes, not attributable navoidable slides, distortions, or other movements of the original ground erlying the embankment.

3. **Borrow Excavation.**—*a.* When material removed from excavation pits trenches is unsatisfactory for use in fill and embankment work or is fficient in quantity for the work to be done, the contractor shall obtain necessary additional material by excavating from the adjacent roadway rom borrow pits as the engineer may direct.

Wherever the natural contour of the ground surface renders it possible, ›ow pits shall be so constructed as to provide effective drainage of the ›vated area.

No "borrow" excavation shall be developed as a "borrow pit" until entire area has been carefully cross-sectioned. Material removed prior he securing of cross-sections will not be paid for.

4. **Ditches.**—*a.* In the construction of approach embankments and lway cuts, special care shall be exercised in locating and constructing hes for the drainage of embankment and cut slopes and the slopes of the ›ining areas. In general, ditches shall be located in natural rather than lled ground, and shall divert the water away from the ends of abutment g walls or other locations likely to become injuriously affected by scour. ›n necessary, in the opinion of the engineer, ditches shall be paved with d-laid cobblestones of satisfactory size and quality.

5. **Measurement of Fill.**—*a.* In the measurement of fill, three general sions shall be recognized, *viz.:*

Backfill shall include all fill material placed in front and rear of abut-ts and retaining walls and around piers required to fill the foundation and trenches up to the elevation of bed of stream or to the original ınd surface or to such other lower elevation or elevations as may be ›ired by the contract or determined by the engineer.

Approach fill shall include all fill material placed in the rear of abut-ts and retaining walls, or upon the roadway embankments adjacent to bridge structure required to replace the formerly existing approach ›ankment material removed by the foundation excavation operations, ›ther with all material required to increase the width or the height of ı approach embankments or to construct new approach embankments.

3. Protection fill shall include all fill material required for the construc of protection embankments.

b. Rip-rap protection placed upon the slopes of embankments an front of abutments and retaining walls and around piers shall not be sidered as fill.

c. Backfill will be paid for at the contract unit price per cubic yard within the limits for which "excavation" is allowed.

d. All volumes of backfill, fill, and embankment not secured from exc tion pits and trenches as provided in Secs. 7*a*, 7*b*, and 12*b* shall, in gen be obtained from roadway or borrow-pit excavations. Whenever, by cross-section method, such measurement is impracticable the metho measuring shall be such as the engineer may determine.

Rip-rap

16. Material.—(*a*) The material to be used for rip-rap protection arc abutments and piers or at other locations where protection from stream s is required shall consist of clean, sound, and durable rock which will become disintegrated by the action of water or by exposure to atmospheric elements. Either boulders or quarried rock may be ı The size and quality of the stones shall be subject to the approval ol engineer.

(*b*) In general, rip-rap deposited in the stream bed as protection arc abutments and piers shall be composed of 50 to 75 % "two-man stone larger. The remaining portion shall be graded from the "two-man,' down to sizes weighing 10 to 15 lb. Stones placed upon the lower por of embankment slopes to protect them against stream scour shall gene be composed of stones of sizes varying from a "one-man" to a "two-n size with a comparatively small percentage of stones of smaller sizes.

17. Placing.—*a.* Stones deposited in the stream bed shall be well n as to sizes and when in position shall provide a comparatively uni protective covering, having the desired depth and area.

b. Stones placed upon embankment slopes shall, if conditions will pe have the bed course placed in a trench at the toe of the slope. The fa outer course shall be random rubble, hand laid to secure an efficient i locking of all face stones and stones placed as backing. The dimensi outer-courses tones normal to the surface of the embankment slope be not less than 6″ and the stones shall be laid with close joints rou perpendicular to the slope which shall be filled with spalls and grav crushed rock. The thickness of the rip-rap layers shall be greater a bottom than at the top. The base course shall be protected by depos rip-rap in front of it, if considered necessary by the engineer.

18. Measurement.—*a.* All volumes of rip-rap shall, in general, be d mined from measurements of material in place. Whenever such mea ment is impracticable by reason of stream-bed conditions, the methc measuring shall be such as the engineer may determine.

Brush Mattress[1]

19. Material.—*a.* The material to be used in the construction of t mattress for the protection of embankments against stream scour generally be composed of willow limbs and saplings of sizes adapted t construction of well-compacted masses of intertwined elements.

20. Construction.—*a.* The general dimensions and details of constru shall be in accord with the contract plans.

21. Placing.—*a.* Sections of mattress shall generally be constructed put in place at such periods of the year as will permit the willow to take and thereby become a more perfect protection at a later date. The mat shall be covered with a layer of topsoil and shall be stayed in positio driving anchor stakes or anchor staples and weighting the mattress stones as the engineer may direct.

22. Measurement.—*a.* Brush mattress shall be measured in p complete, in square yards of top surface area.

Item 103. Untreated Timber Piling[2]

103.1. Description.—This item shall consist of round or square ti piles of the kind and dimensions specified, and in conformity with the p nent designated plans. They shall be driven in accordance with 1 specifications in the location and to the elevation shown on plans o directed by the engineer.

[1] State of Maine. [2] Texas.

03.2. Except for trestle work, timber piles shall be used only below per-
nent ground-water level. Untreated timber piles shall not be used in
er which is infested by marine borers. In general, the penetration for
pile shall not be less than 10′ in hard material and not less than one-third
length of the pile nor less than 20′ in soft material. For foundation work,
piling shall be used to penetrate a very soft upper stratum overlying a
d stratum unless the piles penetrate the hard material a sufficient distance
ix the ends rigidly.

03.3. **Material for Foundation Piles.**—These piles may be of any species
ch will satisfactorily stand driving. They shall be cut from live, sound
s, shall be solid and free from defects, such as injurious ring shakes, large
ound, or loose knots, decay, or other defects which might impair their
ngth or durability. They shall be cut from above the ground swell and
e a uniform taper and shall be free from short bends. A straight line
wn from the center of the butt to the center of the tip shall lie wholly
hin the body of the pile. Piles shall be peeled soon afer cutting. All
ts shall be trimmed closed to the body of the pile. For round piles, the
imum diameter at the tip shall be 8″, and at the butt shall be 12″. The
imum diameter at the butt shall be 20″. Square piles shall be uniform
ross-section, not less than 10 by 12″ for lengths over 30′.

03.4. If possible, piles shall be full length. Where the length required is
ter than is practical to obtain, they may, upon written approval of the
ineer, be spliced. All splices shall be made in accordance with detail
s, prepared to meet the special conditions encountered and which shall
pproved before the piles are driven.

03.5. **Material for Trestle Piles and Foundation Piles for Trestle Bents.**
se piles shall meet the requirements for timber Foundation Piles and
ddition shall be durable timber. The species required will be post oak,
te oak, red or black cypress, or Southern yellow pine (80 % heart).

03.6. **Construction Methods.**—Piles shall not be driven until after the
avation is complete. Any material forced up between the piles shall be
oved to correct elevation before masonry for the foundation is placed.
ber piles shall be driven with a gravity hammer, steam hammer, water
, or a combination of water jets and hammer. The driving of piling with
owers shall be avoided if practicable, and shall be done under written
mission of the engineer only. When followers are used, one pile from
ry group of ten shall be a long pile driven without a follower and shall
used as a test pile to determine the average bearing power of the group.
lars or bands to protect timber piles against splitting and brooming shall
provided where necessary. Timber piles shall be pointed where soil
ditions require it. When necessary, the piles shall be shod with metal
es of a design satisfactory to the engineer, the points of the piles being
efully shaped to secure an even and uniform bearing on the shoes.

03.7. Gravity hammers for driving timber piles shall weigh not less
n 2000 lb. and the fall shall be so regulated as to avoid injury to the
, and in no case shall exceed 20′. Piles shall be driven with a variation
not more than ¼″ per foot from the vertical or from the batter line
cated. All piles raised during the process of driving adjacent piles shall
driven down again if required by the engineer.

03.8. When required, the size and the number of piles shall be determined
actual loading tests. In general, these tests shall consist of the applica-
of a test load placed upon a suitable platform supported by the pile,
ether with suitable apparatus for accurately determining the super-
osed weight and the settlement under each increment of load. The safe
wable load shall be considered as 50 % of that load which, after 48 hr.
lication, causes a permanent settlement, measured at the top of the pile,
not more than ¼″. At least, one pile of each group of 100 piles shall be
s tested.

03.9. **Timber Piles.**—In the absence of loading tests, the safe bearing
es for timber piles shall be determined by the following formulas:

$$P = \frac{2WH}{S + 1.0} \text{ for gravity hammers}$$

$$P = \frac{2WH}{S + 0.1} \text{ for single-acting steam hammers}$$

$$P^1 = \frac{2H(W + Ap)}{S + 0.1} \text{ for double-acting steam hammers}$$

NOTE.—Better formula given on page 1340.

where P = safe bearing power, in pounds.
W = weight, in pounds, of striking parts of hammer.
H = height of fall, in feet.
A = area of piston, in square inches.
p = steam pressure, in pounds per square inch.
S = the average penetration, in inches per blow, for the last 5 tc blows for gravity hammers and the last 10 to 20 blows for ste hammer.

103.10. The above formulas are applicable only when:
(*a*) The hammer has a free fall.
(*b*) The head of the pile is free from broomed or crushed wood fiber.
(*c*) The penetration is at a reasonably quick and uniform rate.
(*d*) There is no sensible bounce after the blow. Twice the height of bounce shall be deducted from H to determine its true value in the formı

103.11. The bearing powers of timber piles, as determined by the fı going formulas, shall be considered effective only when they are less t the crushing strengths of the piles. In general, piles shall be required develop a bearing capacity of not less than 15 nor more than 25 tons. H ever, the character of the soil penetrated, conditions of driving, distribut sizes and lengths of the piles involved, and the computed load per pile sl be given due consideration in determining the reliability of driven pile.

103.12. In case water jets are used in connection with the driving, bearing power shall be determined by the above formulas, from the res of driving after the jets have been withdrawn, or a load test may be appl

103.13. The tops of foundation piles shall be embedded in the conc footing at least 1′, and where seals of concrete deposited in water are u with piles, the piles shall project at least 1′ above the top of the seal concr They shall be cut off level at such elevation that the tops of the piles be always wet.

103.14. Foundation piles for framed bents shall be cut off level appr mately 3′ above the surface of the ground and the cap rigidly secured to e pile by drift bolts extending at least 9″ into the pile.

103.15. Trestle piles shall be cut off level at the elevation on the plans the caps secured as described above. If the cut-off is 10′ or more above ground line, timber piles shall be braced by diagonal cross-bracing compose 3 by 10″ timbers, secured to the lines by ¾″ diameter through bolts.

103.16. In bents of untreated piles the heads of the piles shall thoroughly coated with a thick protective coat of red-lead paint, hot tar asphaltum, or hot coal-tar creosote before the caps are placed.

103.17. The tops of all piling shall be sawed to a true plane as shown the plans, and at the elevation fixed by the engineer. Piles which supp timber caps or grillage work shall be sawed to the exact plane of the sup imposed structure and shall exactly fit it, Broken, split, or misplaced p shall be drawn and properly replaced. Piles driven below the cut grade fixed by the engineer shall be withdrawn and replaced by new anc necessary, longer piles, at the expense of the contractor.

103.18. Basis of Payment.—All piling left in place in the structure will paid for at the contract unit price bid per linear foot for Untreated Tim Piling complete in place, which price shall be full compensation for furnish all piling, all materials, equipment, tools, labor, and incidentals necess to complete the work. No allowance will be made for falsework pili Payment will be made at this price for only the actual number of feet piles left in place in the completed work, and no allowance will be made any piles which are not driven in accordance with the specifications, or ordered by and made acceptable to the engineer.

Item 104. Treated Timber Piling[1]

104.1. Description.—This item shall consist of round or square trea timber piles of the kind and dimensions specified and in conformity with t pertinent designated plans. They shall be driven in accordance with th specifications in the location and to the elevation shown on the plans or directed by the engineer.

104.2. Materials.—Requirements for treated foundation piles, treat trestle piles, and treated foundation piles for trestle bents shall be identi with the corresponding requirements for untreated timber piles with t additional requirements following:

[1] Texas.

04.3. Piles shall be treated with the creosote oil or creosote coal-tar
tions prescribed in the specifications for Timber Structures. The ranges
pressure, temperature, and time duration of treatment shall be controlled
as to result in maximum penetration of the quantity of preservative
cted, which shall permeate all of the sapwood and as much of the heart-
d as practicable. For general construction, not in sea water, piles shall
reated to retain not less than 12 lb. of the preservative per cubic foot of
d by any full-cell process, or not less than 8 lb. by any standard empty-
process.

04.4. **Construction methods** for treated timber piling shall be identical
1 those prescribed for untreated timber piling. The following additional
uirements apply to treated timber piling:

04.5. Treated piles and timbers shall be carefully handled without sudden
pping, breaking of outer fibres, bruising, or penetrating the surface with
s. They shall be handled with rope slings. Cant dogs, hooks, or pike
s shall not be used where such tools will penetrate into the untreated
d.

04.6. After the necessary cutting has been done to receive the cap, the
ls of piles shall be given three coats of hot creosote oil. They shall then
overed with a coat of hot tar pitch, over which shall be placed a sheet
hree-ply roofing felt or galvanized iron, or a covering may be built of
rnate layers of hot tar pitch and loose woven fabric, similar to membrane
erproofing, using four layers of pitch and three of the fabric. The cover
l measure at least 6″ more in each direction than the diameter of the pile,
shall be bent down over the pile and the edges fastened with large-
led nails, or secured by binding with galvanized wire. After the cover
place the cap shall be placed and drift bolted as prescribed.

04.7. All places where the surface of treated piles or timbers is broken by
ing, boring, or otherwise shall be thoroughly coated with hot creosote
nd then with a coating of hot tar pitch. Hot creosote oil shall be poured
the bolt holes before the insertion of the bolts in such manner that the
e surface of the holes shall receive a coating of the oil.

04.8. **Basis of Payment.**—All piling left in place in the structure will be
for at the contract unit price bid per linear foot for Treated Timber
g complete in place, which price shall be full compensation for furnishing
iling, all treating, all materials, equipment, tools, labor, and incidentals
ssary to complete the work. No allowance will be made for falsework
g. Payment will be made at this price for only the actual number of
of piles left in place in the completed work, and no allowance will be
e for any piles which are not driven in accordance with the specifica-
s, or as ordered by and made acceptable to the engineer.

Item 105. Precast Concrete Piling[1]

5.1. **Description.**—This item shall consist of piles precast of Portland
ent concrete made and reinforced in accordance with these specifications
in conformity with the pertinent designated plans. They shall be
en in accordance with these specifications in the location and to the eleva-
shown on the plans or as directed by the engineer.

5.2. **Materials and Design.**—All concrete materials and their prepara-
and placing shall be in accordance with the requirements for Class *D*
rete. (All coarse aggregate to pass a ¾″ ring.) It shall be the charge
e contractor to order materials for and cast and manufacture the requi-
engths and amount of piling to complete the required structure or work.

5.3. Precast concrete piles may be square, circular, or octagonal in
on. If a square section is employed, the corners shall be chamfered at
1″. Piles shall preferably be cast with a driving point and for hard
ng shall preferably be shod with a metal shoe of approved pattern.
g may be either of uniform section or tapered as desired. Tapered piling
not, in general, be used for trestle construction except for that portion
e pile which lies below the ground line; nor shall tapered piles be used
y location where the piles are to act as columns. In general, concrete
shall have a cross-sectional area, measured above the taper, of not less
140 sq. in. and, when they are to be used in salt water, they shall have
ss-sectional area of not less than 220 sq. in.

5.4. The length shall not exceed 30 times the average diameter for
driven through firm soil, and shall not exceed 15 times the average
eter for piles driven to rock through loose, wet soil, or filled ground.

exas.

When lateral support is deficient so that the piles act as columns, they s[illegible] be designed as columns.

105.5. Reinforcement shall conform to the requirements for reinforc steel of these specifications, and the weight and dimensions shall be as sh on plans.

105.6. Reinforcement for precast concrete piling shall consist of lo tudinal bars in combination with lateral reinforcement in the form of hc or spirals. The longitudinal reinforcement shall be not less than 1 % preferably not less than 1½ % of the total cross-section of the pile. reinforcement shall be placed at a clear distance from the face of the pil not less than 2″ and, when the piles are for use in salt water or alkali s this clear distance shall be not less than 3″. The driving point and also top of the pile shall be protected against impact by means of special sp winding or bands designed for this purpose. The reinforcing system s preferably be of the "unit" type, rigidly wired or fastened at all intersect and held to true position in the forms by means of concrete blocks or o suitable device. Where piles exceed 55′ in length, additional longitud reinforcement shall be added throughout the central one-third of the len Piling under retaining walls, abutments, etc., shall be designed to withst the lateral stress induced.

105.7. Where waterproofing is to be used, special specifications wil given and the work shall be in accordance therewith.

105.8. Forms shall be accessible for tamping and consolidation of concrete. Under good weather-curing conditions, side forms may removed at any time not less than 24 hr. subsequent to placing conc but the entire pile shall remain supported for at least 7 days, and shall be subjected to any handling stress until the concrete has set for at leas days, and for a longer period in cold weather, the additional time to determined by the engineer.

105.9. **Casting.**—Piling may be cast in either a vertical or a horizo position. When vertical forms are used, special care shall be exercis puddle and tamp the concrete around the reinforcing and to avoid formation of stone pockets. When horizontal forms are used, the shall not be cast in tiers.

105.10. During the placing of concrete, the forms shall be vibrate tapping with a hammer of wooden maul. Concrete shall be placed con ously in each pile and shall be carefully spaded, puddled, and tamped, marked, special care being exercised to avoid horizontal or diagonal clea planes, and to see that the reinforcement is properly embedded ir concrete.

105.11. **Finish.**—As soon as the forms are removed, concrete piles be carefully pointed with 1:2 mortar, filling up all cavities or irregular

105.12. Trestle piling exposed to view shall be finished above the gr line in accordance with the provisions governing the finishing of con columns. Foundation piling, that portion of trestle piling which w below the ground surface, and piles for use in sea water or alkali soils, not be finished except by pointing as above set forth.

105.13. **Curing.**—Concrete piles shall be cured in accordance witl general provisions governing the curing of concrete as elsewhere prov As soon as the piles have set sufficiently to permit, they shall be rem from the forms and piled in a curing pile separated from each other by spacing blocks. No pile shall be driven until it has set for at least 30 and in cold weather for a longer period, as determined by the engi Concrete piles for use in sea water or alkali soils shall be cured for no than 60 days before being used.

105.14. **Storage and Handling of Precast Concrete Piling.**—For pr piles, the method of storing and handling shall be such as to eliminat danger of fracture by impact or undue bending stresses, in curing or t porting the piles from the molds and into the leads. In general, con piles shall be lifted by means of a suitable bridle or sling attached to th at points not over 20′ apart. In no case shall the methods of handlii such as to induce stresses in the concrete of more than 650 lb. compre per square inch or in the reinforcing steel in excess of 12,000 lb. per so inch, allowing 100 % of the calculated load for impact and shock effect

105.15. In handling piles for use in sea water or alkali soils, special shall be exercised to avoid injury to the surface of the pile.

105.16. Concrete piles when properly designed, constructed, and p may be subjected to loads as determined by tests or formula, but n exceed 300 lb. per square inch of total cross-section at the smallest effe

nt and generally not to exceed 25 tons per pile with a maximum limit of tons per pile.

05.17. **Construction Methods.**—Requirements for equipment and driving e concrete piles will be covered by special specifications.

05.18. **Hammers for Concrete Piles.**—Concrete piles preferably shall driven with steam hammers. Double-acting steam hammers for this pose shall develop an energy per blow at each full stroke of the piston of less than 12,000 ft.-lb., except that in sandy material when used in nbination with a suitable water jet having a pressure of 125 lb. per square n at end of nozzle the above requirements may be modified.

05.19. Gravity hammers, when their use is permitted, shall weigh not than the weight of the pile and the maximum drop shall not exceed 8′.

05.20. **Water Jets.**—Water jets may be used, either alone or in combina- with a hammer. The volume and pressure of the water at the jet zles, and the number of jets used, shall be sufficient freely to erode the erial adjacent to the pile.

05.21. If water jets and a hammer are used for driving, the jets shall be ndrawn and the piles shall be driven by the hammer to secure the final etration. This procedure may be varied if the desired results are not ined.

05.22. Piles shall be driven with a variation of not more than ¼″ per from the vertical or from the batter line indicated.

05.23. **Loading Tests.**—When required, the size and the number of s shall be determined by actual loading tests. In general, these tests l consist of the application of a test load placed upon a suitable platform oorted by the pile, together with suitable apparatus for accurately deter- ng the superimposed weight and the settlement of the pile under each ement of load. The safe allowable load shall be considered as 50 % of load which, after 48 hr. application, causes a permanent settlement, sured at the top of the pile, of not more than ¼″. At least one pile each group of 100 piles shall be thus tested.

05.24. **Concrete Piles.**—In the absence of the loading tests, the safe ing values for piles shall be determined by the formulas given for timber g (p. 1340).

05.26. In case water jets are used in connection with the driving, the ing power shall be determined by the above formulas from the results riving after the jets have been withdrawn, or a load test may be applied.

05.27. **Concrete Piles.**—The bearing values for concrete piles shall be rmined by means of the loading tests above specified. The formulas ified above for timber piling may be used as a rough approximation for ast concrete piles.

05.28. When required, the contractor shall drive test piles of a length and he location designated by the engineer. These piles shall be of greater th than the length assumed in the design in order to provide for any ation in soil conditions.

05.29. Jetting piles shall extend to a good solid stratum. Their carrying city shall be determined by actual tests or, if driven with the aid of a nd for the last five blows of the gravity hammer or last twenty blows he steam hammer, driven without any jet, the same formula may be ied as in the case of driven piles.

05.30. Extensions, splices, or "build-ups" on concrete piles generally be avoided but when necessary they shall be made as follows:

05.31. After the driving is completed, the concrete at the end of the pile be cut away, leaving the reinforcing steel exposed for a length of 40 eters; the final cut of the concrete shall be perpendicular to the axis of pile. Reinforcement similar to that used in the pile shall be securely ned to the projecting steel and the necessary form work shall be placed, being taken to prevent leakage along the pile. The concrete shall be e same quality as that used originally in the pile. Just prior to placing rete, the top of the pile shall be thoroughly wetted and covered with a coating of neat cement. The forms shall remain in place not less than ys and shall then be carefully removed and the entire exposed surface e pile finished as above specified.

05.32. **Methods of Measurement.**—Only the actual number of linear of accepted piles left in place of the completed work shall be measured. llowance will be made for cut-offs or any unaccepted footage. "Build- constructed as required shall be measured as piling, provided that no ance shall be made for "build-ups" which are necessary by damage to iles during driving.

105.33. **Basis of Payment.**—The piling measured as provided above wi paid for at the contract unit price bid per linear foot of Precast Conc Piling, which price will be full compensation for furnishing all mater equipment, labor, and incidentals necessary to complete the work, ex that test piles ordered but not used in the work be paid for as extra work

Item 106. Cast-in-place Concrete Piling[1]

106.1. **Description.**—These piles shall consist of a metal shell drive the location and to the elevation shown on the plans, which shall remai place, and concrete cast in place in the shell, all as prescribed in t specifications.

106.2. **Materials** and requirements for concrete and reinforcing shall be the same as prescribed for Precast Concrete Piling, with the a tional requirement that in all cases the reinforcement shall be of the system, rigidly fastened together and lowered into the shell. No lopse will be permitted.

106.3. **Metal Shells.**—The metal shall be of a sufficient thickness reinforced to such an extent that it will hold its original form and sho signs of distortion after the ore has been withdrawn. The design of shell shall be submitted to and approved by the engineer before any dri is done. After the shell has been driven and the core withdrawn, it sha inspected and approved before any concrete is placed. No payment be made for any shell which has been improperly driven, is broken, or o wise defective, and, if necessary, any such shell shall be removed replaced.

106.4. **Construction Methods.**—No concrete shall be placed unti driving within a radius of 15′ has been completed, or until all the shell any one bent have been completely driven. If this cannot be done, all ing within the above limits shall be discontinued until the concrete ir last pile cast has set at least 7 days, and no load shall be allowed on any cast less than 7 days.

106.5. Concrete shall be placed continuously in each pile, care being to fill every part of the shell and to work concrete around the reinforce without displacing it. No concrete shall be placed in shells containin accumulation of water.

106.6. **Method of Measurement.**—Only the actual number of linear of accepted piles left in place in the completed work shall be measured. allowance will be made for cut-offs or any unaccepted footage.

106.7. **Basis of Payment.**—The piling measured as provided above be paid for at the contract unit price bid per linear foot for Cast-in- Concrete Piling, which price will be full compensation for furnishing driving the shells, for all materials, equipment, labor, and incide necessary to complete the work, except that test piles ordered but not in the work will be paid for as extra work.

Item 107. Plain Rip-rap[1]

107.1. **Description.**—This item shall consist of a protective cours layer of "one-man" stone laid on slopes and at such places as shown o plans or as designated by the engineer, and filled with spalls, and sha constructed in accordance with these specifications and in conformity the depth of course and other details shown on the pertinent cross-secti

107.2. **Material.**—The "one-man stone" shall be free from struc defects, of approved quality, not less than ⅓ cu. ft. in volume, and no than 3″ thick. The width of the stones shall not be less than twic thickness. The spalls shall be of material of similar quality.

107.3. **Construction Methods.**—Slopes, where rip-rap is used, shall steeper than the angle of repose, unless otherwise indicated or dire The stone shall be bedded, one against the other, with the ends in cor The spaces between the larger stone shall be filled with spalls of suitable and all spalls shall be rammed thoroughly into place. The finished su of the rip-rap shall present an even, tight surface true to the lines, gr and sections given.

107.4. **Method of Measurement.**—This item shall be measured by square yard complete in place. The measurement shall be made pa to the face and not necessarily horizontally.

107.5. **Basis of Payment.**—The yardage of completed and accepted measured as provided above shall be paid for at the contract unit

[1] Texas

per square yard for Plain Rip-rap, which price shall be full compensation furnishing and hauling all material, for all quarrying involved, for all r, equipment, tools, and incidentals necessary to complete the work.

Item 108. Grouted Rip-rap[1]

08.1. **Description.**—This item shall consist of a protective course or r of "one-man" stone laid on slopes and at such places as shown on the s or as designated by the engineer, and grouted, and shall be constructed ccordance with these specifications, and in conformity with the depth of se and other details shown on the pertinent cross-sections.

08.2. **Material.**—The "one-man stone" shall be free from structural cts, of approved quality, not less than 1/10 cu. ft. in volume, and not less 4″ thick and 5″ wide.

08.3. **Construction Methods.**—Slopes, where rip-rap is used, shall be no per than the angle of repose, unless indicated or directed. The stone l be bedded, one against the other, with the ends in contact.

08.4. **Application of Grout Filler.**—After the stones have been tamped, ected, and approved, the spaces between the stones shall be filled with ent grout consisting of 1 part Portland cement and 2 parts approved l.

08.5. **Method of Measurement.**—This item shall be measured by the re yard complete in place. The measurement shall be made parallel e face and not necessarily horizontally.

08.6. **Basis of Payment.**—The yardage of completed and accepted work sured as provided above shall be paid for at the contract unit price bid square yard for Grouted Rip-rap, which price shall be full compensation urnishing and hauling all material, for all quarrying involved, for all r, equipment, tools, and incidentals necessary to complete the work.

Item B-6 (L. & U.).—Loaded and Unloaded Test Piles[2]

Description.—(*a*) Loaded test piles shall consist of loading any type ile with twice the loading specified on the plans. Loaded test piles will driven where directed by the engineer and in accordance with these ifications.

) Unloaded test piles shall be of timber and of the same cross-section e piling called for on the plans. It shall be of such length and shall be en as directed by the engineer.

oth types of test piles shall be driven with the same equipment that is e used by the Contractor in driving the piles called for on the plans.

Excavation.—All excavation of the foundation, if any, shall be com- ed before driving is commenced in accordance with the specifications he particular type of piling used.

Method of Testing. (*a*) *Loaded Test Piles.*—After the pile of the type ified by the engineer has been driven in accordance with the require- ts of the specifications for that type, it shall be loaded. The loading erial shall be of any kind approved by the engineer. The loading plat- or box shall be so constructed that readings may be taken directly on pile. This platform or box shall be so built as to carry safely, in the ion of the engineer, an amount of the approved material equal in weight wice the loading shown on the plans. Before the platform or box is tructed, any split or broomed portion of the pile shall be cut off, leaving und surface to support the box.

e loading material shall be applied gradually, as directed by the neer, and shall be so placed that at all times the load will be concentric the pile. The loading material shall be placed within, usually, 24 hr. the pile is driven, unless otherwise directed by the engineer.

e capacity of any pile so tested shall be considered equal to one-half oad carried by the pile without exceeding a total permanent settlement ″ in 48 hr., unless otherwise specified by the engineer.

) *Unloaded Test Piles.*—Piles of this type shall be driven in accordance the specifications for the particular type of piling shown on the plans. piles shall be driven until the capacity as determined by formula is l to that shown on the plans, or until the required penetration is obtained, ss otherwise directed by the engineer. The length of piles driven be as determined by the engineer. In case it is necessary, as deter- d by the engineer, to jet any piles, it shall be done as specified under eated and Treated Timber Piling.

Texas.

[2] North Carolina.

4. Basis of Payment. (*a*) *Loaded Test Piles.*—This work shall be
for at the contract unit price for Loaded Test Piles. This price will inc
all materials, equipment, tools, labor, and work incidental to construc
the platform or box, procuring and placing the loading material, remo
both the platform or box and material, and disposing of same as dire
by the engineer. The piling test will be paid for in accordance with
Basis of Payment for the particular type of piling used. No payment
be made for test loadings made or test piles driven that are not in accord
with these specifications or as directed by the engineer and accepted by

(*b*) *Unloaded Test Piles.*—This work will be paid for at the contract
price for Unloaded Test Piles complete in place. This price will inc
all materials, equipment, tools, jetting, labor, and work incidental the
No payment will be made for test piles driven that are not in accord
with these specifications or as directed by the engineer and accepted by

Item B-7. Sheet Piling[1]

1. Description.—This specification covers only such sheet piling
shown on the plans or is ordered by the engineer to be left in place so
it becomes a part of the finished structure.

2. Material.—The timber, unless otherwise definitely noted upon the
or specified, may consist of any species which will satisfactorily stand dri
It shall be sawn or hewn with square corners and shall be free from w
holes, loose knots, wind shakes, decayed or unsound portions, or
defects which might impair its strength or tightness.

The piles shall be of the thickness specified or directed and shall be
vided with tongues and grooves of ample proportions, either cut from
solid material or made by building up the piles of three planks sec
fastened together. The piling shall be drift sharpened at their lower
so as to wedge the adjacent piles together tightly.

3. Construction.—The tops of the piles shall be cut off to a straight
at the elevation indicated and shall be braced with a waling strip. pro
lapped and joined at all splices and corners. The wales shall preferab
in one length between corners and shall be bolted near the top of each
When in contact with a concrete footing, the waling strip shall be pl
upon the outside of the piles at such an elevation that it can be braced
steel tie rods embedded in the concrete footing.

4. Driving.—Sheet piling shall be driven with either a maul, sl
gravity, or steam hammer, as approved by the engineer. In case it is n
sary, in order to obtain the penetration required, the piling shall be jette

5. Basis of Payment.—Payment will be made at the contract price
thousand feet, board measure, for Sheet Piling, which price will include
cost of furnishing, driving, and cutting off such piles as are required.
ment will be made only for that portion remaining in place and no allow
will be made for material cut off, or for any piling that is not drive
accordance with these specifications, or as directed by the engineer
accepted by him.

Concrete Materials and Construction[2]

1. Composition.—(*a*) Concrete for culvert and bridge structures sha
composed of Portland cement, water, sand aggregate, and stone aggre
mixed and placed by such means and in such manner as to produce in
finished structures a conglomerate mass having uniform texture and stre

Materials

2. Cement.—(*a*) All Portland cement used shall fulfil the physical
chemical requirements of the U. S. Bureau of Standards, *Circular* 33,
the A.S.T.M. Standard Specifications and Tests for Portland Cer
(Serial Designation C9–17), with any subsequent amendments and addit
thereto adopted by the Society.

(*b*) All cement shall be delivered in suitable packages with the brand
the name of the manufacturer plainly marked thereon. All cement
be dry and free from lumps. Except when otherwise provided, the ce
for any given structure shall be of only one brand and produced by a s
mill. All cement shall be sampled after delivery.

(*c*) All cement shall be stored in weatherproof buildings having the f
properly blocked or raised from the ground to prevent absorption of mois
Provision for storage shall be ample, and the shipments of cement as rece

[1] North Carolina. [2] State of Maine

ll be separately stored in such a manner as to provide easy access for ntification and inspection of each shipment. The use of cement damaged weather shall not be permitted, and all damaged cement from whatever se shall be removed immediately from the work.

. **Sand Aggregate.**—(*a*) The sand aggregate for concrete shall consist of d, tough, preferably silicious material; clean, free from mineral or other tings, lumps, soft particles, clayey dust, "clay balls," loam or other eterious vegetable or mineral matter. The particles shall be well graded m a size that will pass a "standard" sieve having four meshes per linear h to a size retained upon a "standard" sieve having 100 meshes per linear h. Not more than 25% and not less than 15% shall pass a "standard" 'e having 50 meshes per linear inch, or a "Tyler" sieve having 48 meshes linear inch.

b) Sand shall not contain more than 5% by weight, of sandy dust terial passing a 100-mesh sieve), and not more than 3%, by weight, shall removable by the elutriation test.

c) Mechanical analysis of the grading shall be made from carefully pre- ed samples taken by the method of quartering.

d) The presence of deleterious organic impurities in sand shall be tested determined by the "Abrams-Harder" field test.

e) Stone screenings may, at the option of the engineer, be used as sand regate either alone or in combination with sand.

f) The particles of stone shall be generally angular and shall be uniformly ded from a size that will pass through a revolving screen having circular nings 3/8″ in diameter to a size that will be retained upon a "standard" e having 100 meshes per linear inch. Stone screening shall not contain e than 5% of fine crusher dust (material passing a 100-mesh sieve). eenings shall have been produced from strong, tough, and durable rock ing a French coefficient of wear of not less than 6, and shall be free from ı, elongated, or laminated particles, disintegrated rock, fine clayey dust, n, or other deleterious vegetable or mineral matter.

. **Stone Aggregate.**—(*a*) The stone aggregate for concrete shall consist articles of broken stone or of gravel originating from uniformly strong, gh, and durable rock having a French coefficient of wear of not less than d shall be free from elongated and laminated particles, disintegrated rock, clayey dust, loam, or other deleterious vegetable or mineral matter. grading of the particles from coarse to fine shall be approximately uni- n, the maximum size depending upon the character and details of the k to be constructed. The volume of the concrete mass, location and cing of reinforcing steel, height of forms, etc., shall be considered in ermining the maximum size or sizes of the stone aggregate. However, following sizes passing screens having circular openings are generally licable:

Structure	Size of Screen
ss concrete 2′ and over in thickness or depth	2½–3″
ss concrete under 2′ in thickness or depth	1½–2½″
nforced-concrete walls 2′ or more in thickness with reinforcing metal 6″ or more apart	2½″
nforced-concrete walls 10″ to 2′ in thickness with reinforcing metal 3 to 6″ apart	2″
nforced-concrete walls under 10″ in thickness	1½″
nforced-concrete beams, girders, and spandrel arch ribs with reinforcing steel spaced 2″ in clear between bars	1½″
nforced-concrete beams, girders, and spandrel arch ribs with reinforcing steel spaced under 2″ in clear between bars	¾–1″
nforced-concrete bridge floors and bridge sidewalk slabs	¾–1½″
nforced-concrete columns, plain	1½–2″
nforced-concrete columns, hooped	¾–1½″
lge hand rails and balustrades	¾–1″
ıcrete placed under water	¾–1″

) The minimum size of particles shall be that retained upon a sieve ing four meshes per linear inch.

:) Broken stone shall contain not over 5%, by weight, of clean crusher t. Gravel shall contain not over 5%, by weight, of sand aggregate terial passing a sieve having four meshes per linear inch), and shall be from mineral or other coating.

. **Premixed Aggregate.**—(*a*) Premixed aggregate in the form of pit or k-run gravel shall be used instead of separate sand and stone aggregates

only when permitted by the engineer, in writing. Its granulometric con sition and other physical properties shall conform to the requirements its sand and stone contents when considered independently. Frequ tests shall be made to determine the relative proportions of sand and st aggregates and the granulometric composition of each. Irregular may, at the option of the engineer, be corrected by the addition of sand c stone aggregates, as conditions may require to secure a satisfactory mate Irregularities rendering it impracticable to secure a satisfactory comb aggregate shall be considered ample reason for discontinuing the us premixed aggregates and for requiring that such material be screened used as separate sand and stone aggregate.

(*b*) Premixed aggregate containing an inadequate proportion of s aggregate may, at the option of the engineer, be used in concrete, prov the contractor will undertake, in writing, to provide at his own expense additional quantity of cement required to produce concrete having strength of the grade contemplated in comparison with the quality requ for a 1:2 relation of sand and stone aggregates. The contractor shall bear the expense involved in making the laboratory tests required for determination of the premixed aggregate relation.

6. One-man Stones.—(*a*) One-man stones to be used in rubble or Cy pean concrete and as bond or dowel stones in construction joints shall cor of angular fragments of tough, dense, and durable rock, having a Fre coefficient of wear of not less than 6. They shall be free from seam other structural defects, foreign substances, and coating of any charac In general, the maximum size of the stones shall not exceed that which man can lift and readily move about, while the minimum shall not inc stones measuring less than 6″ in their shortest dimension.

7. Water.—(*a*) All water used in concrete or used for curing conc shall be subject to the approval of the engineer. It shall be fresh, reason clear and free from oil, acid, alkali, and vegetable matter, or other deleter substances.

(*b*) An effective means shall be provided for the gaging of the mi water for concrete. The device used for gaging shall be controllable to extent of varying the quantity of water to be used per batch within a missible range of 1 pt. per bag of cement used in the concrete mix.

Field Tests

8. Test Specimen Molds.—(*a*) Molds for field and laboratory use s be produced from steel piping so fabricated as to be adapted to the pro tion of concrete cylinders 6″ in diameter by 12″ long.

(*b*) To provide for the easy removal of the cylinders from the mol longitudinal element of the original pipe shall be machined out and open space so produced shall be closed by forcing the metal edges into c contact with clips and bolts or by ring clamps surrounding the molds.

c. The inside of the molds shall be smooth and the sharp edges shall h all burrs and roughness removed. The ends shall be cut true and para Each mold shall be provided with a steel base plate measuring (10 by 10 3/8″).

9. Preparation of Specimens.—(*a*) For the purpose of determining quality of concrete being produced, test specimens shall be taken at s intervals as the engineer may direct.

(*b*) In general, the concrete used for specimens shall be taken from middle of the batches while being discharged from the mixer drum. H ever, the engineer may for specific reasons require that the test sample taken from the first or the last concrete discharged from the mixer or fr the mass of concrete after it has been subjected to the operations of plac

(*c*) The concrete shall be carefully compacted in the molds by the us a slicing tool prepared from a piece of 3/8″ diameter rod flattened for a len of 5 to 6″ to a thickness of 3/32 to 1/8″ to form a blade-like tool, the full len of which shall be approximately 15″ exclusive of the handle produced bending the rod to form a hand grip of convenient shape.

(*d*) It is important that the test cylinders be free from honeycomb "pockets" of stone aggregate. It is especially important that, so far possible, all the mixing water be retained by the molds within the conc mass.

(*e*) Special care shall be exercised in finishing the top ends of the cylind true and even to permit a uniform bearing in the testing machine. Finish may be executed in either of two ways:

1. By filling the specimen molds up to within 1/4 to 3/8″ of their tops, th after a period of 15 to 20 min. has elapsed, completing the cylinders

ping with neat cement paste and using a cover plate of heavy plate glass of metal to shape the top surface, the plate being adjusted to perfect tact with the top edge of the molds. Plate glass or metal plates shall erally be 8 by 8″ in size and shall be oiled on under side to permit their ly removal when the concrete has taken a "green set."

o prevent excess shrinkage the cement paste must be mixed to form roximately a "normal consistency" mass and should be prepared several utes in advance of its application to the cylinder ends.

By the use of a plaster mason's trowel to remove excess concrete erial from the top surfaces of the specimens and to dress these surfaces and even by carefully troweling them flush with the top edge of the imen molds.

o prevent evaporation of the moisture the specimens shall be covered wet cloths as soon as troweled. These cloths are to be kept moist.

). **Stripping, Marking, and Curing Specimens.**—(*a*) Cylinders shall ain in the molds 24 hr. before being removed. Immediately upon oval they shall be carefully marked for identification, preferably with k paint, and shall be cured by burying in wet sand until the expiration e test period.

) Identification marks, if placed upon the top ends of the cylinders while concrete is green, shall be so executed as to not impair or injure the surface ing while testing.

Proportioning

. **Grades and Strengths.**—(*a*) Concrete for culvert and bridge structures be divided into four grades, *viz.:* A, B, C, and D.

) Concrete of each grade when mixed in accordance with the specified irements for mobility and time of mixing and molded into test cylinders diameter by 12″ long shall develop not less than the following compres- strengths in pounds per square inch at the ages of 7 and 28 days ectively:

Grade	7 Days	28 Days
A	2100	3000
B	1500	2300
C	1000	1700
D	700	1200

pressive strength shall be determined from an average of five cylinders d at each age.

) If the test specimens fail to fulfil the strength requirements for 7-day and the 28-day tests show the strength desired for the grade specified, concrete shall be considered acceptable.

. **Proportions of Aggregates.**—(*a*) In general, the relation of sand to e aggregate shall be 1 part sand to 2 parts stone measured by weight or the corresponding volumes. Preference will be given to the former. ations from this ratio will be subject to the approval of the engineer. quantity of sand contained in the stone aggregate shall be taken account its relation to the total sand content of the mix. The accurate measure- t of the aggregates used per batch of concrete is essential.

. **Relation of Cement to Aggregates.**—(*a*) The quantity of cement to sed per batch of concrete shall be determined by the engineer and shall, eneral, be dependent upon the quantity necessary to produce from the egates to be used a workable mix which will secure, in the finished cture, concrete having strength equal or greater than that assumed by conditions of the design. The concrete shall also possess the density, hness, and other physical properties necessary for durability. Con- nt with these conditions the contractor may be required to change the ent content of the mix to conform with variations in the gradings of the egates.

) Whenever considered advisable, in the opinion of the engineer, the tity of cement to be incorporated in the mix shall be determined by ratory tests, which shall be made by and at the expense of the Commis- However, the contractor shall supply and ship f.o.b. cars the quanti- of materials required for such tests. If test specimens are prepared at bridge site he may be called upon to provide the labor necessary for preparation.

. **Mobility.**—(*a*) The mobility (consistency or workability) of the rete is mainly dependent upon the thoroughness of the mixing and the tity of water contained in the mix. The mobility of the concrete mix

shall be at all times as the engineer may direct. However, in general, quantity of water used shall be sufficient to produce concrete, the mc component of which is of a saturated, sticky, semiplastic consistency, sh ing no free water when removed from the mixer, and when transporte barrows, buckets, chutes, etc., it shall show no appreciable segregation of component materials. When deposited in forms it shall settle in place become thoroughly compacted with a comparatively small amount of s ing, slicing, or other manipulating. When transported in metal ch placed at an angle of 30° with the horizontal it will slide (not flow) t place of placing.

(*b*) The top surface of concrete having the mobility described above show a cement film upon the set concrete. Accumulations of inert, c like material commonly known as "laitance" result from the use of an e: sive quantity of water in the concrete mix and are indicative of low-stre concrete.

15. Mixing.—(*a*) The concrete shall be mixed in the quantities requ for immediate use and any which has developed initial set, or which not reach the forms within 30 min. after the water has been added, shall be used.

(*b*) Unless hand mixing is especially permitted by the engineer, the mi shall be done in a batch mixer of approved size and type which will insur uniform distribution of the materials throughout the mass so that mixture is uniform in color and semiplastic in appearance. The mi shall continue for a minimum time of 1½ min. after all the materials assembled in the drum, during which time the drum shall revolve at the s for which it was designed, but shall make not less than 14 nor more 20 r.p.m. The mixer shall be equipped with an attachment for autor cally locking the discharging device so as to prevent the emptying of the n until all the materials have been mixed together for the minimum required. The entire content of the drum shall be discharged before materials are placed therein for the succeeding batch.

(*c*) The mixer shall have a capacity of not less than a "one-bag batch concrete.

(*d*) The first batch of concrete materials placed in the mixer shall con an additional quantity of sand, cement, and water sufficient to coat inside surface of the drum without diminishing the mortar content o mix. Upon the cessation of mixing for any considerable length of the mixer shall be thoroughly cleaned by flushing it with a stream of v from a hose or by the use of some other satisfactory method.

16. Hand Mixing.—(*a*) When hand mixing is permitted, the sand a gate shall be spread evenly upon the platform and the cement spread it. The sand aggregate and cement shall then be mixed dry with sh or spades (mixing with hoes shall not be permitted) until a uniform co attained, after which the mixture shall be formed into a "crater" and quantity of water necessary to produce a mortar of desired mobility pc thereon. The material upon the outer portion of the "crater" ring then be shoveled to the center and the entire mass sliced and turned a uniformly wet mortar is produced. The stone aggregate which shall been previously wetted shall then be deposited upon the mortar and entire mass turned and returned with shovels or spades until all the s particles have become thoroughly coated with mortar. Hand-mixed bat shall not exceed ½ cu. yd. in volume. Mixing platforms shall be w tight and shall be of ample size readily to accommodate the work invo Hand mixing will not be permitted for concrete placed under water.

17. Retempering.—(*a*) All mortar and concrete shall be used while before the initial set has begun. No retempering of mortar or con shall be allowed.

Placing and Curing

18. Handling and Placing.—(*a*) Concrete, after the completion of mixing, shall be handled rapidly to the place of final deposit. When ch are used they shall be so designed as to transport the concrete at or nea place of depositing so as to avoid rehandling. Transportation by succe shoveling within the forms shall, in general, not be permitted. Ch shall be of metal, or, if of wood, shall be metal lined.

(*b*) The concrete shall be deposited in such a manner as will prevent separation of the ingredient materials and permit its thorough compa without jarring, deforming, or displacing the forms or the metal reinf ment. Dropping the concrete from too great a height, throwing it too g

stance, depositing large quantities at one point and running or working ong the forms, or other practices tending to cause segregation shall not ermitted. In general, concrete shall not be dropped from a height greater 5′. It shall be compacted and worked into contact with all parts of forms by agitating it with a straight spade or a slicing tool kept moving nd down until the mass has settled into place and all surplus water has forced to the surface. Especial care shall be taken to break down any ing action and to prevent the formation of "pockets of stone." The rete shall be thoroughly compacted around all reinforcing metal to re maximum bond therewith. Care shall be taken not to jar the form or the reinforcement metal after the concrete has taken its initial set.

) Wherever practicable, concrete shall be deposited continuously for monolithic section of the work. All floor slabs, sidewalk slabs, and lar thin sections of the work shall be placed full thickness.

) In general, all concrete in piers, abutments, and retaining walls shall leposited in horizontal layers of uniform thickness throughout. The kness of layers shall not exceed 8 to 10″. An incomplete layer shall be with a vertical construction joint.

) In general, no concrete shall be placed in pier, abutment, or other vations without forms. When placing without forms is permitted by engineer, especial care shall be taken that lumps of earth or other foreign ter falling from the sides of the excavation do not become buried in concrete.

) Horizontal layers so located as to produce a construction joint at a tion wherein a "feather edge" will nominally be produced in the succeed- layer shall be so formed by inset form work that the succeeding layer end in a body of concrete having a thickness of not less than 6″.

) Each layer of concrete shall generally be left somewhat rough to re an efficient bonding with the next layer above. A succeeding layer ed before the underlying layer has become set shall be compacted in a ner that will entirely break up and obliterate the tendency to produce nstruction joint between the layers.

) Wooden spacer struts and braces within the forms shall be removed n the placing of concrete has reached their height. These pieces of material must not be buried within the concrete mass.

) Layers completing a day's work or placed just prior to discontinuing porarily concrete operations shall generally be cleaned of all "laitance" her objectionable material as soon as the concrete has become sufficiently to retain its form. To avoid visible joints so far as possible upon face ce, the top surface of the concrete adjacent to the forms shall be finished eing smoothed with a plaster mason's trowel.

) In all cases where face surfaces are to have a mortar surface, whether ed or not, a spade or slicing tool shall be worked between the concrete the form to force back the stone aggregate and to produce a dense mortar

) In all cases where, on account of the obstructions produced by rein- ing metal, shape of forms, or any other uncontrollable condition, difficulty countered in puddling the concrete adjacent to the forms, the mortar ent of the mix shall be brought into proper contact with interior surfaces vibrating the forms. The vibrations shall be produced by striking their ide surfaces with wooden mallets or by any other means satisfactory e engineer.

) Top surfaces of bridge seats, backwalls, parapet walls, curbs and hand- bases, retaining walls, roadway slabs, etc., shall generally be "struck" a straight-edge or "floated" after the stone aggregate has been forced w the finished elevation of the concrete. The use of a layer of mortar roduce the final finished surface shall not be permitted. Surfaces which ultimately support the pedestals of girders, trusses, columns, or other al superstructure parts shall be finished smooth, true, and even. To re the production of roadway and sidewalk slabs having the thickness cated upon the plans, their top surfaces shall be screeded to correct con- s by the use of strike boards supported upon firm guides or screeding s. It is important that the top surface of roadway and sidewalk slabs ccurately finished to true elevation and grade.

n) Care must be taken that face surfaces of forms and the surface of forcement do not become splashed with concrete which will take its al set before becoming covered by the concrete being placed in the work. ashes that have taken such initial set shall be carefully removed and the ace of the form again wetted or oiled.

(*n*) In no case shall the work on any section or layer be stopped or te rarily discontinued within 18″ below the top of any face, unless the de of the work provide for a coping having a thickness less than 18″, in w case, at the option of the engineer, the construction joint may be mac the under side of the coping.

(*o*) In placing concrete in columns the work shall be discontinued a elevation of the bottom of the girders, beams, or slabs taking bearing them for a period of not less than 2 hr. before continuing the placin concrete in the girders, beams, or slabs. Each column shall be examine accumulations of "laitance" or other foreign matter which, if present, be removed in preparation for resuming the placing of concrete. The ing of concrete in column forms shall not be discontinued at an interme point between base and top.

(*p*) All concrete in through girder spans shall be placed complete single operation. All concrete in slab spans shall be placed complete single operation up to the tops of wheel guards or hand-rail bases. T-beam spans shall, unless otherwise permitted by the engineer, be structed in a single operation. When the concrete of the T-stem is perm to be placed independent of the slab section, the construction joint sha located at the under side of the slab and the bond between stem and shall be a mechanical one produced by embedding 2 by 4″ wooden b having a length approximately 4″ less than the width of the stem in th surface of the concrete when placed. To provide for the uniform spa of the blocks and their ready removal when the concrete has taken sufficient to hold its form, the blocks shall be beveled ¼″ on the side ends and shall be firmly nailed upon a board at a distance of 1′ cent center. The blocks shall be thoroughly oiled to facilitate their r removal from the concrete.

(*q*) When new concrete is placed upon the top of a preceding day's or upon the top of concrete that has become fully set especial care sha take that the outer edge of the new layer of concrete shows at all tin fringe of mortar to assure perfect contact with the surface of the exi concrete.

(*r*) The placing of concrete in solid and open spandrel arches invo volumes too great for monolithic construction shall be subdivided as engineer may direct. In general, the order of construction or sequen the work shall be shown upon the plans and shall include details of k construction joints in arch rings and their locations together with the de for the attachment of spandrel walls to the outer edge of arch rings. Sec shall be so arranged that initial stresses will not be created in the r reinforcement.

(*s*) The placing of concrete in solid and open spandrel arches shall erably be a single continuous operation and to secure a proper loadin the centering shall involve symmetrical placing about the crown of the . The extrados of the arch ring shall be, unless shaped by an extrados f screeded to correct contour and finished with a wooden float to secur even, uniform surface.

(*t*) Spandrel wall concrete shall not be placed until after the arch cente has been released. The placing of concrete in the copings of spandrel and in hand rails shall not be commenced until all spandrel wall concre in place and a sufficient length of time has elapsed to permit the arc adjust itself to the loads produced by the latter.

(*u*) Construction joints in abutments, piers, and retaining walls ar portions of superstructures wherein the conditions involved may resu the seepage of water through the joints and the future discoloratio exposed surfaces shall contain water baffles consisting of a sheet of zi galvanized iron 6″ in width set vertically at a distance of not less 3″ from the exposed face surface and embedded one-half its width in concrete below the joint and the remaining width in the concrete above. sections or strips of metal shall overlap not less than 6″ at their ends.

19. Placing in Cold Weather.—(*a*) In general, no concrete shall be m and placed when the air temperature is at or below 35°F. When the mi and placing of concrete are permitted, in writing, by the engineer, sp precautions shall be taken to avoid the use of materials containing f and efficient and adequate means shall be provided to prevent the chi or freezing of the concrete. At the time it is placed in the forms, the conc shall have a temperature not lower than 50°F. The protection affo shall conform to the requiremnts of Sec. 27, Curing Concrete. The met of heating the concrete materials shall be approved by the engineer, but

k shall be done entirely at the risk of the contractor. The use of salt ny other chemical to prevent freezing or to procure quick setting of the rete shall not be permitted.

. **Placing under Water.**—(*a*) Placing of concrete in water shall be nitted only (*a*) when contemplated by the contract plans and (*b*) when orized by the engineer in writing. A description of the method and pment to be used shall be submitted by the contractor and approved he engineer before the work is started.

) Cofferdams shall be sufficiently tight to prevent any current through space in which the concrete is to be deposited. Pumping will not be nitted while the concrete is being placed nor until it has become fully set.

) The method used shall be such as will not permit the washing of the ent from the concrete mix. In no case shall concrete be dumped from ows or shoveled into the water or allowed to fall through the water in er open or closed metal chutes.

) The tremie, when used, shall consist of a tube 12 to 16″ in diameter, tructed in sections with flanged couplings fitted with gaskets. It be so constructed as to permit its initial charging without dropping the rete through the water. In operating the tremie it shall be kept filled l times and the discharge end shall be raised only sufficiently to permit concrete to move uniformly down the tube. Special care shall be cised in moving the tremie to secure a practically uniform and level ice upon the concrete in place, and to prevent the loss of the charge. ne event of losing the charge the tremie shall be refilled as described for nitial filling. The means supporting the tremie shall be such as to nit the free movement of the discharge end over the entire top surface ne work and shall permit its being rapidly lowered, when necessary to ent a too rapid flow or a loss of the entire charge.

The bucket, when used, shall be so constructed that it cannot be ped until it rests upon the surface upon which its charge is to be placed. eneral, this construction shall consist of a base frame extending below doors forming the bottom of the bucket a sufficient distance to permit n to open downward and outward when tripped or unlatched. The ions of the frame opposite the ends of the doors shall be of solid sheet il to prevent the initial movement of the concrete in these directions n the bucket is being dumped. The sides of the bucket below the eleva- of the under side of the doors shall be of open construction, permitting free displacement of the water. The portion of the frame coming in act with previously placed concrete shall have a bearing area which will ent the loaded bucket from slumping into the concrete a distance cient to produce a movement of water tending to dislocate its cement ent. The top of the bucket shall not be closed.

In operating the bucket it shall be completely filled and when lowered the water its descent shall be sufficiently slow to prevent all unnecessary ement of the water. In the operation of discharging and lifting the et it shall be raised slowly to avoid, so far as possible, a movement of water above the concrete. The concrete shall be placed in layers having surfaces as uniform and even as possible.

) The bags, when used, shall be of jute or other coarse cloth. They be about two-thirds filled with concrete, and shall be carefully hand ed in header and stretcher order to secure an efficient interlocking of whole mass.

) When possible, the concrete shall be placed continuously from start nish in so far as that portion of the work to be placed under water is erned. In order to assure a thorough bonding between the layers, the pment for mixing, transporting, and placing the concrete shall be ade- e to produce a rate of progress which will permit the placing of each eeding layer before the preceding layer has taken its initial set. The of "plums" shall not be permitted in concrete placed under water. To ent the formation of "laitance," the concrete shall be agitated as little ssible while being placed. All laitance or other foreign matter shall be ved from the surface of a complete portion of the work before the placing ncrete by the usual methods is commenced thereon.

. **Placing on or against Set Concrete.**—(*a*) Whenever new concrete is placed on or against concrete which has fully set, the surface of the oncrete shall, unless thoroughly cleaned of all "laitance" and objection- material before becoming set, be roughened and carefully cleaned of ance" and foreign matter and be drenched with water until saturated. forms, if they are not in close contact with the set concrete, shall be

tightened against its faces, and the new concrete placed therein shall, be c pacted in a manner assuring maximum bond between the new and the material. If necessary, in the opinion of the engineer, the new conc shall contain an excess mortar content.

22. **Bonding Construction Joints.**—(*a*) The construction joints produ between layers of concrete placed intermittently in piers, abutments, retaining walls shall be bonded to prevent displacement by sliding or overturning. Approved hard, sound, and durable stones of "one-ma size may be used in structures having a width of 4′ or more, while in narro structures metal dowels or a mechanical bond secured by producin "mortise and tenon" interlock shall be used. When the concreting of lower layer is complete, its surface shall be prepared for bonding the la to be superimposed upon it before the concrete has taken its set.

(*b*) When "bond" or "dowel" stones are to be used they shall be h placed as specified for the placing of stones in rubble or Cyclopean conc (see Sec. 23 (*b*), Rubble or Cyclopean Concrete), except that stones hav a distinct stratified structure shall be set with the "grain" vertical to construction joint.

(*c*) Metal dowels shall consist, in general, of rods having a diamete not less than ½″ and a length of not less than 1′. However, when appro by the engineer, metal secured from scrap bar, pipe, castings, etc., may used, provided such metal has ample cross-section and is free from scale. In general, dowels shall be staggered and their distance cente center shall not exceed 3′.

(*d*) When a "mortise and tenon" bond is to be used the "mortise" shal produced by forcing the ends of 6 by 6″ timbers into the unset concrete depth of 3 to 4″. The holes so produced shall be staggered and shall exceed 2′ center to center. To facilitate their ready removal from the c crete after it has taken its set the ends of the scantlings shall be sligh beveled and thoroughly oiled.

23. **Rubble or Cyclopean Concrete.**—(*a*) Whenever provision is m upon the plans for the use of rubble concrete in abutments, piers, and ret ing walls, its use shall be permitted in portions of these constructions hav a width of 4′ or more. The stones or "plums" used shall consist of ang fragments of tough, dense, and durable rock of the size commonly know "one-man stone," *i.e.*, stones not larger than one man can readly lift. T shall be free from seams or other structural defects, foreign substances, coatings of any character.

(*b*) The stones shall be hand placed (not cast or thrown into the concr in "rack and pinion" order, not less than the width of a man's foot a nor nearer than 1′ to the inside of the forms and shall be forced down the fresh concrete.a depth equal to one-half their size. When strati stones are used, they shall generally be laid upon their natural bed. E layer of stones shall be covered with concrete to a depth equal to the of the stones, before a succeeding layer shall be placed. The conc surrounding the stones shall be thoroughly compacted so as to fill all irre larities and cavities in their surfaces. Under no circumstances sha course of stones extend higher than 2′ below the top surfaces of abutments piers upon which the bridge superstructure is to be placed. When the t of abutments and piers are finished with copings, the uppermost cours stones shall be located at least 1′ below the under side of copings.

24. **Joints.**—(*a*) The locations and details for expansion joints in retai walls, abutments, etc., shall be strictly adhered to.

(*b*) Where sliding joints are to be provided at the ends of slab, T-beam, girder spans having a length less than 30′ the bridge seat or other bea areas shall be screeded true to grade and carefully finished by the use plaster mason's trowel and when the concrete has become thoroughly the bearing areas shall, unless otherwise provided upon the plans, be cove with a layer of asphalt-treated roofing felt before the superstructure conc is put in place. To insure free movement consistent with the length superstructure spans, the thickness of the layer of felt shall vary correspo ingly and shall, in general, be made of sheets of heavy roofing felt swab with liquid asphalt between each sheet. Thickness of layers shall vary follows:

Span Lengths	Layer Thickness
10′ and less	⅛″
11–20′	¼″
21–30′	⅜″

einforced-concrete T-beam and girder spans of lengths over 30′ shall, in ral, be provided with bronze expansion plates or other approved devices ermitting free expansion and contraction movements. Unless especially ided otherwise upon the plans, no reinforcement shall extend across xpansion joint.

In general, the locations of construction joints shall be planned in nce of the placing of concrete. These joints shall be located and con-cted so as to impair the strength and appearance of the structure the possible. Diagonal or otherwise deformed construction joints in ments, piers, retaining walls, slabs, beams, and girders shall not be itted.

) In general, every structural element of a bridge structure shall be pleted without discontinuing the placing of concrete, if practicable. alled "construction joints" produced by discontinuing the work at the of a day or at other times shall be predetermined as to location, if ble. These joints shall be located perpendicular to the principal lines ress and generally at points of minimum shear.

Construction joints shall be produced as specified in Sec. 18, Handling Placing, and Sec. 22, Bonding Construction Joints.

. **Cleaning Mixers, Tools, Etc.**—(*a*) All mixers, chutes, barrows, spades, g tools, etc., shall be cleaned from all adhering mortar at the end of each work or at other times whenever the mixing and placing of concrete is orarily discontinued for any considerable length of time. It is also sable that splashes and spatters of mortar adhering to the interior ces of forms and to metal reinforcement be removed at the time of ntinuing placing, since they can be most readily removed at that time. must be removed before the placing of concrete is resumed. If not ved, these accumulations of inert material produce two unsatisfactory itions, *viz.:* they either cleave from the surfaces of the forms and remain orarily embedded in the face surface of the concrete to become dis-rated at a later period, or they remain firm upon the forms and cleave the surfaces of the new concrete when the forms are removed, leaving surfaces rough and irregular.

. **Protection of Work.**—(*a*) Concrete in place shall not be subjected to ting, jarring, or other movement tending to produce incipient fractures g the period of "green" set. Form carpenters, carpenters' helpers, other laborers shall not be permitted to walk or work upon the concrete it has become sufficiently set to break or crumble under their feet, but ot yet attained a hard set. Carpenters and their helpers engaged upon onstruction of forms above green-set concrete shall work upon properly ructed scaffoldings and walkways.

. **Curing Concrete.**—(*a*) In order to develop the desired strength, ul attention shall be given to the proper curing of the concrete. In hot her all concrete surfaces exposed to premature drying shall be protected the direct rays of the sun by means of canvas, straw, sand, or other actory covering, and shall be kept continually moist by sprinkling or wise for a period of at least 10 days after placing. Other precautions sure proper curing of concrete shall be taken by the contractor as ted by the engineer.

Concrete placed in cold weather shall be amply protected to retain its l temperature (not lower than 50°F.) for at least 72 hr. after the placing nplete and until the concrete has become set. The temperature shall be maintained above freezing, 32°F., for an additional 7 days and the ete shall be kept moist throughout the entire 10-day period. Concrete ing injury by frost shall be removed and replaced at the contractor's nse.

Reinforcement

Metal Reinforcement.—(*a*) Reinforcement metal used shall be factured in accordance with and shall in all respects fulfil the physical chemical requirements of the A.S.T.M. Standard Specifications for -steel Concrete Reinforcement Bars (Serial Designation A15-14) with ubsequent amendments and additions thereto adopted by the Society, t that it shall be produced only by the open-hearth process and that med bars shall not be machined to obtain a uniform cross-section before g. Unless otherwise provided, only steel of "structural-steel grade" be used. Wherever structural-steel shapes are to be used, they shall the physical and chemical requirements of the A.S.T.M. Standard fications for Structural Steel for Bridges (Serial Designation A17-16) with

any subsequent amendments and additions thereto adopted by the Soc Preference shall be given to bars and shapes manufactured by the open-he process. No enrolled material will be accepted.

(*b*) Unless otherwise provided upon the plans, all reinforcement sha plain round bars. It shall be free from mill and rust scales, dirt, oil, p or other foreign matter and, if ordered by the engineer, shall be scraped cleaned by the use of scrapers, wire brushes, or other satisfactory me Steel shall be stored on skids or other supports at a satisfactory height a the ground.

(*c*) The bending of reinforcement to conform to the dimensions show the plans shall be accurately done. In general, the radii of bends sha equal or greater than twice the diameter of the bar measured from the in of the curved metal; however, the radii for stirrups shall be equal to or than the diameter of the bar. All bending shall be done cold.

(*d*) All reinforcement shall be accurately placed in the locations show the plans and adequate means provided for securely holding it in co position during the placing of concrete in the forms. Whenever the reinf ment is to be held out of contact with the forms by supporting it upon bl precast mortar blocks of approved dimensions shall be used. Likewise of bars in girders, T-beam stems, etc., shall be separated by the use of pr blocks. The use of pebbles, flat pieces of broken stone, bricks, metal or wooden blocks shall not be permitted.

(*e*) The locations of the reinforcement are, with few exceptions, ma matically determined to conform with the loadings assumed in the d and variations therefrom, produced by "foot and spade" placing of metal, radically affect the strength. The placing of the reinforcement a concreting progresses without definite means for holding it in its co location shall not be permitted.

(*f*) Reinforcement shall be placed well in advance of the concreting shall be inspected and approved by the engineer before any concrete is p in contact with it.

(*g*) No deviation in sizes shown on the plans, or in the spacing o arrangement of the bars will be allowed except by special permission o engineer, in writing. An application for permission to substitute other for those shown on the plans or for permission to splice reinforcement shall be accompanied by sketches showing the complete layout prop Splices shall be avoided at points of maximum stress and shall be stag where possible. The number of splices shall be minimum. No splices w permitted in the main reinforcement of beams and girders. Splices in cent bars shall be staggered. Splices shall be designed to develop strength of the bar without exceeding the allowable bond stress, but i absence of an actual design a minimum lap of 40 diameters shall be All splices shall be firmly seized with not less than four turns of wi intervals of 6 to 10″, depending upon the size of bars, the shorter sp being used upon the larger sizes of bars. When required by the engi cable clamps shall be used to fasten reinforcing bars. Such clamps develop the full strength of the bar. Splicing by means of welds shal be permitted.

(*h*) Reinforcement showing splashes of dried mortar shall be cle before being imbedded in the concrete.

Forms

29. Forms.—(*a*) All forms shall be well built, substantial, and unyiel securely braced, strutted, and tied to prevent motion and distortion concrete is being placed in them and amply strong to safely support, in tion to the weight of the concrete, all superimposed loads (runways, ba loads, workmen, scaffolding, etc.), placed upon them. In proportic forms, falsework and centering concrete shall be treated as a liquid weig 144 lb. per cubic foot for vertical loads and 72 lb. for horizontal pressu

(*b*) Concrete surfaces as related to form construction shall be divided two classes, *viz.:*

1. Forms for unexposed surfaces, such as the back surfaces of abut breast walls and wing walls; the back surfaces of retaining walls, and sur of abutments, piers, etc., located below the beds of streams and the fini surfaces of backfill around abutments, piers, and retaining walls.

2. Forms for exposed surfaces which include all surfaces not consic as unexposed.

(*c*) All back surfaces of retaining walls to a depth of 18″ below the to these walls and all front or face surfaces of abutments and piers to a d

′ below the finished ground surface or to a greater depth, if, in the opinion he engineer, there is a possibility of a deepening of the waterway due to ır, shall be treated as exposed and shall be constructed accordingly.

l) All lumber used for exposed surface forms shall, unless otherwise vided, consist of sized and dressed tongue and groove lumber, free from e knots, knot holes, cracks, and other defects affecting the strength he lumber or the accuracy of the finished concrete surfaces. When er than tongue and groove lumber is to be used it shall be dressed on side and both edges (d3s) to a uniform thickness and width and of the lity described for tongue and groove material. The thickness of tongue groove lumber shall be not less than 1¼″ and of plain dressed lumber not than 1½″. To provide for reusing the lumber a greater number of es it may be dressed on both sides.

) Lumber used for unexposed surface forms shall be of uniform width, ight-edged, and dressed on one side (d1s) to a uniform thickness of not than 1½″. It shall be free from loose knots, knot holes, cracks, wane, or er defects rendering it unsuitable for form work. When permitted by engineer, undressed lumber of uniform thickness and width, otherwise lling the requirements for lumber dressed on one side, may be used for xposed surface forms.

) Lumber for studding, walings, struts, braces, etc., shall be free from ds, crack, and other structural defects rendering it unsatisfactory for the pose for which it is to be used.

) Forms shall be built to conform accurately to the dimensions, location, tours, and details shown on the plans. The faces of forms against ch the concrete is to be placed shall be dressed smooth and uniform and l be free from winds, twists, buckles, and other irregularities. They l be constructed by experienced and capable workmen and shall be ciently tight to prevent the leakage of cement and mortar through the ts. In general, forms shall be constructed so that they can be removed n the bottom upward and shall be designed so that they may be removed hout damage to the concrete. In general, forms shall be provided for work. The placing of concrete in excavated pits and trenches without ns shall be permitted only in exceptional cases and at the discretion of engineer (see Sec. 18 (*e*), Handling and Placing).

h) Except in the construction of forms for round-ended piers, the lagging heeting shall be placed horizontal. For long abutment, pier, and retain- wall forms requiring two or more lengths of lagging, the joints in adjacent es shall be staggered to secure additional rigidity. Forms built to be ted and removed in sections shall be provided with an ample means for ling the sections rigidly to correct alignment and grade.

) All corners within the forms shall be fitted with chamfer strips, mitered heir intersections, to prevent spalling of the concrete during the removal he forms. In general, chamfer strips shall not have a greater width than ′ nor a less width than ½″. The size to be adopted for a given portion he work shall depend somewhat upon the general dimensions involved. vision shall be made for the chamfering of the top edges of abutment ge seats and wing walls, tops of piers, and retaining walls, tops of side ough) girders, roadway curbs, etc., by nailing chamfer strips inside the ns. These strips serve as screeding strips for the finishing of the top ace of the concrete when it is placed. They are usually made ¾ to 1″ width. Unless otherwise provided, all chamfer strips shall produce in concrete plain, flat surfaces.

) Form material or form sections used more than once shall be carefully ned from adhering mortar and other accumulations of foreign matter, ny.

k) The forms for beams, girders, columns, and spandrel arches shall be onstructed as to permit the sides to be removed without disturbing the ports.

) All sawdust, chips, blocks, shavings, and other foreign matter within forms shall be removed before depositing concrete in them. Forms, e especially column and thin reinforced wall forms shall, wherever essary, be built with removable pieces of sheeting to permit thorough ring.

n) All forms shall be held rigidly to correct alignment and location by ple supports and braces. In all cases where metal anchorages or ties hin or through the face forms are required to hold the forms in their ect position, such anchorages or ties shall be of ample strength and shall o constructed that the metal work can be removed to a depth of 2″ from

the face surface of the concrete without injury or damage to such surfa by spalling or otherwise. The cavities produced by the removal of metal shall be carefully filled with a mortar mix similar to that containec the concrete in which the cavities occur.

(*n*) Forms shall be inspected and approved before placing concrete wit them.

30. Unwatering Forms.—(*a*) Unless otherwise provided, all forms sl be unwatered before concrete is placed in them. Pumping will not be p mitted from the inside of forms for abutments, piers, and retaining w while concrete is being placed. Moving water shall not be permitted come in contact with fresh concrete. In general, cofferdams, caissons, cr or other devices used to exclude water from foundation excavations shall constructed to provide free access to all exterior portions of the substruct forms, both for their construction and their inspection.

31. Preparing Form Surfaces.—(*a*) In order to insure the non-adhes of the mortar to the forms the inside surfaces shall be uniformly coated w raw paraffin or other non-staining mineral oil, soaped, or thoroughly wet with water (except in freezing weather). If soap is used it shall be mi with sufficient water to produce a thin jelly-like substance. When fo are used more than once they shall be carefully cleaned at each setting a recoated with oil or soap.

(*b*) Whenever forms are constructed several days in advance of fill them with concrete they shall be kept moist or otherwise protected agai warping of the lagging and other defects produced by the drying out of lumber.

(*c*) Forms used for producing openings in hand rails or other portion the work shall be thoroughly saturated by immersing in water or otherw to prevent swelling by absorption of water from the concrete.

32. Removal of Forms.—(*a*) Location, weather conditions, mater used, and the character of the structure involved shall be considered determining the time for the removal of forms.

(*b*) In general, forms shall not be removed until sufficient time has elap subsequent to the complete placing of the concrete to permit the devel ment of a set which will give forth a distinct "stoney ring" when the c crete is struck with a small hammer. (Frozen concrete shall not be tested.)

(*c*) Forms shall be removed from columns before removing the falsew or shoring from beneath the adjacent beams and girders so that the condi of the column concrete may be determined.

(*d*) The falsework or shoring originally placed under the forms s remain in place until its final removal. The supports must be removed manner which will permit the concrete to assume uniformly and gradu the stresses due to its own weight.

(*e*) Methods of removal tending to produce shocks, jars, and fractu of the concrete shall not be permitted. In general, the removal of fo shall be from the bottom upwards.

(*f*) Forms shall not be removed at any time without the consent of engineer. However, such consent shall not in any way relieve the c tractor of his responsibility for the work.

Arch Centering and Falsework

33. Arch Centering.—(*a*) Foundations for the falsework and centering arches when not consisting of solid rock or other unyielding soil mate shall be reinforced by the use of piles, grillage, or other means to supp without appreciable settlement the loads to be superimposed thereon.

(*b*) The timbering of the falsework and centering shall be securely a rigidly constructed and shall, for all spans having a length greater tl 20′, be supported upon adjustable wedges or other approved devices facilitate lowering of the centering or other supports under full cont evenly and gradually, without subjecting the concrete of the arch span shock or an uneven distribution of pressure.

(*c*) The lagging or sheeting of the arch centering shall be narrow a shall otherwise fulfil the requirements for exposed surface forms. All une joints or other irregularities due to the curvature of the centering shall planed off.

(*d*) All lagging and timbering shall be thoroughly saturated with wa prior to commencing the construction of the arches, and shall be kept saturated until the concreting of the arch ring or of the main arches is co plete and a satisfactory length of time, in the opinion of the engineer, l

osed to render the concrete not only self-supporting but also of sufficient ength safely to support the structure loads to be imposed thereon. When strength has been secured the centering and falsework shall be permitted dry out gradually as a means of slowly relaxing their support. As soon he arch ring has or the main arches have, in the opinion of the engineer, umed a permanent set the placing of the concrete in spandrel walls or in er deck construction may proceed.

e) The contractor shall provide upon the main arch forms or centering, he engineer may direct, suitable check blocks for the purpose of observing deflections produced as the work progresses.

f) Detail plans of falsework and centering for concrete arch spans shall supplied by the contractor for the approval of the engineer whenever uired by a general note on the contract plans or requested so to do by the ineer in writing. Detail plans shall show in addition to elevation, plan, l section views, the mathematical development of the design and the d and sizes of material to be used. All details shall be shown upon draw-s of standard size (see Proposal and Contract Requirements—Size of ns) and when the work is complete the original plan, on tracing cloth, ll be supplied to the Commission for its Bridge Division file.

4. **Falsework.**—(*a*) All falsework used for supporting reinforced-concrete erstructures shall be composed of timbers having ample cross-sectional as to resist without deformation or appreciable settlement the loads osed upon them. It shall be well built, rigid and unyielding, securely ced, strutted, and tied to prevent distortion and motion tending to duce vibration and deformation of the superstructure forms.

b) When the vertical members of falsework consist of piles or when ned or other falsework is supported upon piles, the piles shall be driven secure a safe load resistance of at least 15 tons per pile (see Piles and e Driving).

c) When falsework is supported upon mud sills the sills shall consist of east two layers of timbers, the upper layer being laid transversely with under or bottom one. The foundation pressures resulting from the osed loads upon mud sills (falsework, forms, fresh concrete, scaffolding, nways, etc.) shall, in general, not exceed the following:

. For firm sand, gravel, rotten rock, very firm clay, and other similar soils in confined thick beds	2 tons per square foot
. For loose sand and gravel and ordinary clay soils in confined thick beds	1 ton per square foot
. For soft clay and firm alluvial soils	½ ton per square foot

ll arch centering and falsework shall be subject to the approval of the ineer, but the work shall be done entirely at the risk of the contractor, engineer's approval in no way relieving him of his responsibility.

d) Forms supported upon falsework shall be provided with a satisfactory ns for their adjustment in the event of settlement or deformation of the ework due to overloading or other causes.

Surface Finish

5. **Surface Finish.**—(*a*) In general, all face surfaces of concrete, whether duced by contact with the forms or by screeding, floating, troweling, or er means, shall be true and even, free from depressions or projections shown on the plans, and from "honeycomb," stone pockets, and other ects resulting from defective forms and improper placing; nor shall these aces show layers of accumulated "laitance" or other foreign materials. thermore, these surfaces shall be free from injurious seams, flaws, cracks, ken edges, or other defects.

b) As soon as the forms are removed, all stone pockets, "laitance" ers, chips, shavings, or other foreign matter shall be removed by the use chisels or by other means satisfactory to the engineer, and the cavities produced shall be filled as he may direct. The cavities shall be freed n loose dust and the surrounding concrete shall, if dried, be thoroughly urated with water before the cavities are filled.

c) Small "water cavities," air voids, pits, and other defects not detri-ntal to the strength of the structure shall be filled with mortar of the same as that used in the concrete containing the defects. This mortar shall applied with a wooden float and shall be thoroughly forced into the holes ill them completely. All excess mortar shall be removed by "cutting"

it away with the edge of the float. Cavities, pits, and other defects up vertical surfaces shall be filled by floating upward to force the mortar i contact with the uppermost surfaces of the holes.

(*d*) Bolt or other holes resulting from form ties shall be carefully fill Mortar shall not be applied to dried-out concrete surfaces.

(*e*) Under no circumstances shall mortar be used for the purpose of p ducing a plaster coating to cover irregularities of surface resulting from war buckles, mismatches of lagging, or other defects in forms.

(*f*) Concrete surfaces as related to their final finish shall be divided i three classes, *viz.:*

1. Surfaces permanently covered with water, backfill, and approach after the completion of the work or intended to be so covered (top surf of roadway slabs, back surfaces of the breast and wing walls of abutmen back surfaces of retaining walls, and surfaces of abutments, piers, e located 2′ below the elevation of extreme low water, or an equal depth bel the finished surfaces of backfill around abutments, piers, and retaining w shall be so considered) shall be subject to the general conditions noted abc

2. Surfaces not exposed to general view (sides and bottoms of inter girders and stringers, bottom surfaces of floor slab or of slab spans, a other surfaces as the engineer may decide shall be considered as so expos shall be subject to the general conditions described above. Furthermc these surfaces shall, when finally finished, show no depressions or projecti beyond the general surface. Form marks shall not be removed, but surfaces which, in the opinion of the engineer, are of this class shall pres a clean-cut, workman-like appearance.

3. Surfaces exposed to general view (sides and bottoms of exterior gird and stringers, spandrel arches, roadway curbs, hand rails, cantileve brackets under sidewalks, girders at tops of substructure bents, and exposed surfaces of abutment breast and wing walls, piers and retaining w down to a depth of 2′ below extreme low water or an equal depth below finished ground surface, or to a greater depth, if, in the opinion of the en neer, there is a possibility of a deepening of the waterway, and any ot surfaces as the engineer may decide shall be so considered) shall be "rubb mortar" finished.

(*g*) A "rubbed-mortar" finish shall be produced as follows:

As soon as the mortar used in filling surface defects has taken a firm s the surface to be finished shall be moistened and thoroughly rubbed ground with a carborundum brick or similar tool to remove from such s faces all inert sand and cement materials and to eradicate all impressi of form work. When the surface under treatment has been rubbed t smooth and even surface, the pasty material adhering to the surface sh be entirely washed off and the surface shall be again wet rubbed until a sm accumulation of fine-grained paste is produced. This paste shall not removed, but shall be carefully spread with a moist whitewash brush to fo a uniform, very thin coating upon the surface of the concrete. This coat shall remain undisturbed until it has attained a firm set.

(*h*) Final surface finishing shall not be done in freezing weather or wh the concrete contains frost. In cold weather the preliminary rubbing nec sary to remove the inert sand and cement materials and surface inequalit may be done without the application of water to the concrete surfaces.

36. **Sidewalk Finish.**—(*a*) Unless otherwise provided, the finishing sidewalk areas upon bridge structures shall consist essentially of the followi treatment, following the general screeding of the surface as specified in S 18 (*k*), Handling and Placing. A margin 4″ in width shall be outlin adjacent to the base of the sidewalk hand rail by tautly stretching a co having a diameter of $\frac{3}{16}$ to $\frac{1}{4}$″ upon the freshly screeded surface, followi which this margin or strip shall be finished smooth by the use of a plas mason's trowel, and in this operation the cord shall be pressed firmly into t concrete to produce a clearly defined margin. Similarly, a margin 6″ width shall be defined smooth upon the curb side or edge of the sidewa When the sidewalk upon the bridge does not connect with a concrete sidew upon the approaches to the bridge, the ends of the sidewalk shall be finish with a margin 4″ in width to conform with the finish along the curb; otherw the finish at the ends shall be such as to match the margins used upon t slab of the approach sidewalk. Following the finishing of the margins above specified the entire midarea of the sidewalk slab shall be finished wi a short wooden float which shall be moved in small circles to produce a she like pattern upon the surface of the concrete. Care shall be exercised not "float" beyond the cord marks upon either margin. Unless otherw

ovided upon the plans, the sidewalk area shall not be divided into long-dinal sections by transverse grooves cut with the tool used for that rpose upon ordinary sidewalk work. Transverse grooves produce es of weakness in the sidewalk slab which tend to develop cracks at these ations.

Precast Sections

37. **Forms or Molds.**—(*a*) Forms or molds for precasting hand rail or other tions shall fulfil all specified requirements for form materials and construc-n. Metal or metal-lined forms shall be used only when the smooth faces they produce harmonize with other face surfaces of the structure.

38. **Casting.**—(*a*) The metal reinforcement shall be placed and rigidly d in the position shown upon the detail plans.

(*b*) The methods used for depositing and placing the concrete shall fulfil specified requirements for this work. See Sec. 18, Handling and Placing. e surface of the concrete corresponding to the open side of the form or ld shall be floated, troweled, or otherwise finished to produce a uniform, en surface texture comparable to the "formed" surfaces of the section or mber. Proper curing conditions shall be provided.

39. **Stripping and Finishing.**—(*a*) Precast sections shall not be removed m the forms until the concrete has attained ample set to permit the work be done without danger of spalling, cracking, or other injury.

(*b*) The finishing of the concrete surfaces shall not be undertaken until the ncrete has attained a "hard" set. The finishing of surfaces by breaking the "green" set shall not be permitted.

40. **Assembling.**—(*a*) In the assembling of precast sections the methods of ing, transporting, and otherwise handling the sections shall be such as not subject them to stresses producing fractures, incipient cracks, or other ects.

b) Assembled sections shall be held rigidly in position by braces, struts other supports until incorporated in the finished structure.

Floor Slabs on Metal Structures

41. **Floor Slabs on Metal Structures.**—(*a*) The materials, methods of nstruction, etc., used in placing reinforced-concrete floor slabs upon metal dge structures shall, in general, conform to the specified requirements for construction of bridge superstructures composed entirely of reinforced ncrete.

b) Especial care shall be taken during construction operations to protect metal portions of the structure against disfigurement by spatters, splash-, and smirches of mortar and concrete. Following the placing of the ncrete, the metal surfaces shall be thoroughly cleaned without injuring the nt upon them. This work shall be done at the contractor's expense.

Miscellaneous

42. **Foundation under Concrete.**—(*a*) Where concrete is to be placed on excavated earth surface other than rock, especial care shall be taken not loosen or disturb the bottom of the excavation and the final removal of terial to the finished foundation elevation shall not be made, except in the e of concrete roadway slabs on bridge approaches, until immediately ore the concrete is to be placed. The excavation elevations shown on the ns for abutments, piers, and retaining walls shall be considered only as proximate and may be changed to elevations securing satisfactory founda-n conditions. Placing of concrete in excavations shall not be commenced il the depth and character of the foundations have been examined and proved by the engineer. All rock or "near-rock" foundation surfaces ll be free from loose pieces, cut to firm surfaces, leveled, or stepped, if essary, and thoroughly cleaned to secure a proper bond with the concrete.

43. **Drainage.**—(*a*) Scuppers, grating, down pipes, or other openings or ures intended to provide a means of drainage for the roadway or sidewalks ll be provided as shown on the plans or as required by the engineer. cial attention shall be given to the matter of providing discharge clear of steel or other parts of the structure subject to injury therefrom.

STATE HIGHWAY DEPARTMENT OF TEXAS

Item 85. Concrete

85.1. **Description.**—Concrete shall be composed of Portland cement, fine l coarse aggregate, each measured separately and accurately by volume, l water, mixed as provided in these specifications, and shall be constructed

where, and of the form, dimensions, and design shown on the plans. Co crete shall be classified and proportioned by volume as follows, and in event shall the number of bags of cement of 94 lb. each used per cubic ya of concrete in place be less than the number required below:

Class	Parts Aggregate to 1 Cement	Bags Cement to Cubic Yard
A	6	6.0
B	7½	5.0
C	9	4.5
D	5	7.0

85.2. The engineer shall regulate the proportion of fine to coarse aggreg to secure the maximum density and, in general, the proportions in terms the three ingredients shall approximate the following normal ratios for several classes of concrete:

Class *A* 1-2 -4
Class *B* 1-2½-5
Class *C* 1-3 -6
Class *D* 1-2 -3

85.3. When the class of concrete required is not expressly indicated the plans, the following requirements shall govern:

1. For superstructure, arch rings, walls, or other parts of a structure hav a least dimension less than 1′, and for all heavily reinforced concrete exc where Class *D* is used, and for concrete deposited under water, Class concrete shall be used.

2. For substructures having a minimum thickness of at least 1′, and which all steel is embedded at least 3″ (5″ where below low water), and d not carry calculated stress, Class *B* concrete shall be used.

3. For unreinforced footings, not deposited under water, Class *C* concr shall be used.

4. For railing, rail posts, and other very thin sections Class *D* concr shall be used.

85.4. **Materials.**—The coarse aggregate shall consist of broken stone gravel conforming to the following requirements:

Broken stone shall consist of clean, tough, durable fragments of r (excluding schist, shale, or slate) of uniform quality throughout, shall free from an excess of thin or elongated pieces, soft or disintegrated sto dirt, organic, or other injurious matter occurring either free or as a coating the stone. All stone shall have a per cent of wear of not more than 6. limestone shall meet the requirements of the soundness test.

85.5. Gravel shall consist of clean, hard, durable, uncoated pebbles hav a per cent of wear of not more than 15 (abrasion test for gravel) and shal free from soft, thin, or laminated pieces, disintegrated stone, dirt, orga or other injurious matter occurring either free or as a coating on the sto Where reinforcing steel is to be used, gravel shall be free from salt and alk Pit or bank-run gravel shall not be used.

85.6. **Grading.**—Coarse aggregate shall be well graded, and when tes by laboratory methods, 95 to 100 % shall be retained on the ¼″ screen all classes.

85.7. For Class *A*, 95 to 100 % shall pass the 1½, and 40 to 75 % shall p the ¾″ screen. For massive sections of a concrete Class *B* grading may used when expressly permitted.

85.8. For Class *B*, 95 to 100 % shall pass the 2½, and 40 to 75 % shall p the 1¼ and be retained on the ¾″ screen.

85.9. For Class *C*, 95 to 100 % shall pass the 3, and 40 to 75 % shall p the 1½ and be retained on the 1″ screen.

85.10. For Class *D*, all shall pass the ¾, and 30 to 75 % shall pass ½″ screen.

85.11. When *A* concrete is required in thin sections less than 8″ in th ness, the material shall all pass the ¾″ screen.

85.12. Coarse aggregate conforming in all respects to the above requ ments except grading may be used, provided that concrete made from s material meets the requirements of the strength test hereinafter specifiec

85.13. Fine aggregate shall consist of sand, or a combination of sand not more than 50 % of stone screenings, conforming to the follow requirements:

85.14. Sand shall be composed of clean, hard, durable, uncoated gra free from lumps, soft or flaky particles, loam, organic or other injuri

atter. Where reinforcing steel is to be used, sand shall be free from sal · alkali.

85.15. Stone screenings shall consist of the clean, dustless product resulting om the crushing of stone, meeting all the requirements for coarse aggregate cept for grading, and free from lumps.

85.16. Fine aggregate shall be well graded from coarse to fine and shall eet the following requirements:

Passing the ¼" screen	95–100%
Passing 20-mesh sieve	35– 70%
Passing 50-mesh sieve	5– 30%
Passing 100-mesh sieve	0– 5%

Weight removed by elutriation test not more than 3%.

85.17. When subjected to the color test for organic impurities, the fine gregate shall not show a color darker than the standard color.

85.18. Fine aggregate conforming to all requirements except grading and lor, and mortar strength hereinafter specified, may be used, provided that ncrete made from such material shall meet the requirements of the concrete rength test hereinafter specified.

85.19. Cement shall conform to the requirements for Portland cement escribed in U. S. Department of Agriculture *Bulletin* 1216. The cement all be stored in such a manner as to permit easy access for proper inspection d identification of each shipment, and in a suitable weather-tight building ich will protect the cement from dampness.

85.20. Water shall be clean, clear, free from oil, acid, alkali, or vegetable atter and shall not be used until the source of supply has been approved. at any time the water from this source shall become of unsatisfactory ality or insufficient quantity the contractor may be required to provide tisfactory water from some other source. Water of doubtful quality all be tested in briquettes as provided under Mortar Strength of this ecification and the test results shall be equal to those made from water of own satisfactory quality.

85.21. **Mortar Strength.**—When the fine aggregate is mixed with Portland ment in the proportion of 1:3, the tensile or compressive-strength ratio mpared to Ottawa-sand mortar briquettes of the same proportions and nsistency shall be not less than 100% at 7 and 28 days.

85.22. **Concrete Strength Test.**—Concrete materials may be submitted the following test and shall be considered to pass the concrete strength st when the following strength requirements are fulfilled. In no case, wever, shall aggregate be used which contains more than 3% of material movable by the elutriation test, nor shall coarse aggregate contain more an 1½% of clay or dust.

85.23. The coarse aggregate, fine aggregate, cement, and water proposed r use shall be mixed in the same proportions and to the same consistency at they are to be used in the work, and tested as prescribed in U. S. Department of Agriculture *Bulletin* 1216, and at least the following compression rengths shall be obtained, for the several classes:

Class	7-day Test	28-day Test
A	1300	2000
B	1000	1700
C	900	1500
D	1700	2500

85.24.—The seven-day requirements may be waived. The exact proporns may be varied, with the approval of the engineer, to obtain the strength sired and the new proportions used in the work, but the proportions of ment to total aggregate shall not be less than hereinafter prescribed, only ch proportions shall be used as will produce a workable mixture, and no owance shall be made the contractor for altered or additional work or aterial involved in the reproportioning.

85.25. **Hydrated Lime.**—This material delivered to the work in the original ckages may be used to an amount not exceeding 10% by volume of the rtland cement. Each package shall be clearly marked to show the brand, e net weight, the name of the manufacturer, and place of manufacture. shall comply with the current specifications of the A.S.T.M.

85.26. For hand-mixed concrete the lime shall be well mixed while dry. shall be considered as an additional material, not as replacing any cement.

The use of hydrated lime, unless otherwise specified, is optional with t contractor except that it shall not be used in concrete deposited und water, and no compensation for it will be allowed the contractor.

85.27. All sampling of materials shall be as required in U. S. Departme of Agriculture *Bulletin* 1216. Cement shall be packed, shipped, stored, a inspected as prescribed in *Bulletin* 1216.

85.28. The method of storing and handling aggregate on the work shall such as to avoid segregation of sizes, and mixture of the material with mu dust, or trash. When deemed necessary, the engineer may order the use platforms for the storage of coarse aggregate. Aggregate shipped in dir cars or containers, or that becomes mixed with weeds, dirt, or foreign mater or that is not uniform, or the component parts of which have become seg gated, shall be rejected. Preferably, no aggregate shall be stored or dump on the roadbed.

85.29. **Construction Methods.**—All equipment, tools, and machinery us for hauling materials and performing any part of the work must be approv by the engineer and must be maintained in satisfactory working conditio

85.30. Falsework for supporting concrete work shall be built on founc tions of sufficient strength to carry the load without appreciable deformatic Falsework which cannot be founded on solid footings must be supported ample falsework piling. Falsework shall be designed to carry the full loa coming upon it. For single-span bridges falsework shall be given a perm nent camber equal to $\frac{1}{20}''$ per foot of clear span. Multiple-span bridg shall be given the amount of camber specified on the plans. In gener double wedges or other suitable means shall be provided for constructing fal work and forms to correct lines. On important structures, when request by the engineer, the contractor shall submit plans for falsework and for for checking and approving before the falsework is constructed. No ext compensation will be allowed for falsework.

85.31. Wood or metal forms shall be constructed of materials sufficient strength to hold the concrete without bulging between supports. T material to be used in wood forms for exposed surfaces shall be sized a dressed lumber, free from knot holes, loose knots, cracks, splits, or otl defects affecting its strength, the accuracy, or the appearance of the finish concrete surfaces, and in general shall be at least $1\frac{1}{2}''$ thick. Tongue a grooved material may be required by the engineer. If metal forms are us all bolt and rivet holes shall be countersunk so that a plane, smooth surfa will be obtained.

85.32. In designing forms and centering, the concrete shall be treated a liquid weighing 150 lb. per cubic foot for vertical loads, and 85 lb. per cu foot for horizontal pressure. The unsupported length of the wooden colum and compression members shall not exceed thirty times the diameter least side.

85.33. Forms shall be so designed and constructed that they may be moved without injury to the concrete. Blocks and bracing shall be remov with the forms and in no case shall any portion of the wood forms be l in the concrete. Special attention shall be paid to the ties and braci and where the forms appear to be insufficiently braced, or unsatisfactor built, either before or during construction, the engineer shall order the wc to be stopped until the defects have been corrected to his satisfaction. the forms bulge or sag at any point when the concrete is placed in them, t portion of concrete causing the distortion shall be immediately removed a the forms properly repaired and strengthened before continuing the wo The forms shall be so constructed that the finished concrete shall be of t form and dimensions as shown on the plans and true to line and grade.

85.34. Forms shall be filleted at all sharp corners and shall be given a be in the case of all projections, such as girders, copings, etc., sufficient to insu their easy removal.

85.35. To insure a first-class surface finish on the concrete, the forms sh be painted with a colorless oil, or some other satisfactory means taken prevent the concrete adhering to them. The forms shall be thorough drenched with water immediately before the concrete is placed in the They shall be inspected immediately preceding the placing of concrete, a bulging or warping shall be remedied, and all dirt, sawdust, shavings, or oth débris within the forms shall be removed.

85.36. For narrow walls where access to the bottom of the forms is n readily attainable otherwise, the lower form boards shall be left loose that they may be removed for cleaning out all chips, dirt, sawdust, or oth extraneous material immediately prior to placing concrete.

85.37. Form lumber which is used a second time shall be thoroughly aned and shall be free from bulge, splits, or warps.

85.38. **Measuring Materials.**—All materials shall be separately and curately measured by volume, unless otherwise specified, and each batch all be uniform. The coarse and fine aggregate shall be measured loose d separately. No computed change in volume for moisture content all be considered. A bag of cement (American) as packed by the manu-cturers and weighing 94 lb. shall be considered 1 cu. ft. The contractor all furnish and use approved measuring boxes, pans, or mechanical devices, ich in operation will give the exact volumes of coarse and fine aggre-te required for the several classes of concrete required, and so designed d plainly marked that the inspector can accurately and conveniently eck the quantities of each aggregate actually being used.

85.39. **Consistency.**—The quantity of water to be used shall be deter-ned by the engineer, and not varied without his consent. The contractor all furnish and use with the mixer an approved adjustable water-measuring vice which will prevent excess water flowing into the mixer in order that consistency may be under positive control, and all batches may be of the ne consistency.

85.40. In general, the minimum amount of water shall be used which will oduce the required workability. The mortar shall cling to the coarse gregate, and shall show no free water when removed from the mixer. e concrete when being transported in a clean metal chute at an angle of ° to the horizontal shall slide, and not flow, and when dropped directly m the discharge chute of the mixer, shall flatten out at the center of the e, but shall stand up and not flow at the edges. The upper surface of set concrete shall show a cement film upon the surface, but shall be free m laitance. In no case shall an amount of water be used sufficient to use the collection of a surplus on the surface.

85.41. **Mixing Conditions.**—The concrete shall be mixed in the quantities quired for immediate use and any which has developed initial set, or which not in place within 30 min. after the water has been added, shall not be ed. No concrete shall be mixed while the air temperature is at or below °F. without the approval of the engineer. Retempering of concrete or rtar will not be allowed.

85.42. **Mixing.**—The mixing shall be done in a batch-mixer of approved pe which will insure the uniform distribution of the material throughout mass so that the mixture is uniform in color and smooth in appearance. e mixing shall continue for a minimum time of 1½ min. after all the redients are assembled in the drum, during which time the drum shall volve at the speed for which it was designed but shall make not less than nor more than 20 r.p.m. The mixer shall be equipped with an attachment satisfactorily locking the discharging device so as to prevent the emptying the mixer until all the materials have been mixed together for the minimum ne required. The entire contents of the drum shall be discharged before y materials are placed therein for the succeeding batch. The mixer shall equipped with bucket and boom delivery unless otherwise permitted by engineer, have a capacity of not less than three bags of cement per ch of concrete of the composition herein specified, and a speed regulator hold the mixer to its normal speed of revolution.

85.43. **Hand Mixing.**—Hand mixing will not be allowed except with the ecific permission of the engineer on very small jobs or in case of an emer-ncy. When hand mixing is permitted it shall be done on a water-tight tform. The fine aggregate and cement, shall first be mixed until a uni-m color is attained and then spread over the mixing board in a thin layer.

85.44. The coarse aggregate, which shall have been previously drenched, ll then be spread over the fine aggregate and cement in a uniform layer l the whole mass turned as the water is added.

85.45. After the water has been added, the mass shall be turned at least six es, and more if necessary, to make the mixture uniform in color and smooth ppearance. Hand-mixed batechs shall not exceed ½ cu. yd. in volume.

85.46. **Placing.**—No concrete shall be poured in foundation until the ineer has approved the depth and character of the foundation, nor shall concrete be poured in forms until the engineer has approved the placing he steel.

85.47. The concrete shall be placed in the forms immediately after mixing l in such manner as to avoid the separation or segregation of the aggregate. e mixing plant shall be equipped and arranged so as to permit the mixing l placing of the concrete quickly and uniformly.

85.48. In depositing the concrete, care shall be taken to fill the for entirely, and to compact the concrete by continuous tamping, slicing, ar spading, but not to bulge or distort the forms or to disturb their alignmen Any porous section shall be removed at the expense of the contractor.

85.49. When concrete is deposited through chutes, the angle of the san with the horizontal shall be such as will allow the concrete to slide slow and without separation of the aggregate. The delivery from the spout sha be as close as possible to the point of deposit. Chutes shall preferably l of metal, but if of wood, metal lined, they shall be kept clean and free fro material adhering to their sides and shall be thoroughly flushed with wat before and after each run.

85.50. The use of long chutes will be allowed only with written permissi of the engineer, and such permission will not be given for work which w be exposed to salt or brackish water.

85.51. Pipes when used shall be kept full of concrete, and the dischar end shall be kept buried in fresh concrete, and shall meet the requiremen prescribed for tremies.

85.52. Depositing large quantities at one point in the forms, and runni and working it along the forms, will not be permitted. Special care sh be taken, in filling the forms, to work the coarser aggregate away from t face of the forms and to force the concrete under and around the reinforc ment. The concrete shall be worked with a steel slicing rod, or other sat factory implement, in such a manner as to bring a thick layer of mortar contact with the forms and reinforcement, and to prevent the formation pockets of stone.

85.53. All faces shall be spaded. Portions inaccessible to slicing rod spade shall be worked by vibrating the forms by wooden mallets or directed by the engineer. After the concrete has taken its initial set, ca shall be exercised to prevent walking on the concrete, to avoid jarring t forms or knocking or straining projecting reinforcement.

85.54. Concrete shall be placed in continuous horizontal layers, in gene not over 1′ in thickness. When a monolithic layer cannot be completed one operation, it shall be terminated with a vertical bulkhead. No feath ing out will be tolerated. The batches of concrete shall follow the precedi batch closely before any initial set can take place in order to prevent lir of demarcation between batches. Successive horizontal layers shall bonded to each other. The surface of each layer shall be left rough or otl provision for bonding made as required.

85.55. Joints.—Joints may be constructed joints or expansion joints either the sliding or filled type.

85.56. Construction Joints.—Wherever the work of placing concrete delayed until the concrete shall have taken its initial set, the point of sto ping shall be deemed a construction joint. So far as possible the location construction joints shall be planned in advance and the placing of concr carried continuously from joint to joint. Those joints shall be perpendicu to the principal lines of stress and, in general, shall be located at points minimum shear.

85.57. Where dowels, reinforcing bars, or other adequate ties are not sho on the plans or required by the engineer, keys shall be made by imbeddi water-soaked beveled timbers of a size shown on the details, or as direct by the engineer, in the soft concrete, which shall be removed when the cc crete has set. In resuming work, the surface of the concrete previou placed shall be thoroughly cleaned of dirt, scum, laitance, or other s material, with stiff wire brushes, and if deemed necessary by the engine shall be roughened with a steel tool. The surface shall then be thorougl washed with clean water and painted with a thick coat of neat cement mort after which theplacing of concrete may proceed.

85.58. No concrete work shall be stopped or temporarily discontinu within 18″ of the top of any finished surface, unless such work is finish with a coping having a thickness less than 18″, in which case the joint sh be made at the under line of the coping.

85.59. In construction joints exposed to view where seepage of water particularly objectionable, a metal baffle strip, preferably of copper, zi or sheet lead, shall be inserted. The strip shall be placed not less than from the face of the concrete and shall extend into each section of the concr a distance of not less than 2″.

85.60. Sliding joints shall be constructed as provided at ends of sla girders, or beams or between walls, etc. The surface of the supporti concrete shall be given a smooth finish and covered with two layers of thr

y roofing felt or other material as prescribed to separate the concrete. All etal sliding surfaces shall be coated with graphite and grease just before ing placed in position, and care shall be exercised to prevent any deposit concrete which will interfere with the sliding action.

85.61. **Concreting in Cold Weather.**—No concrete shall be placed when e atmospheric temperature is below 35°F. unless permission to do so is anted in writing by the engineer. When such permission is given, the llowing requirements shall govern:

85.62. The contractor shall furnish sufficient canvas and framework, or her type of housing to enclose and protect the structure in such a way at the air surrounding the fresh concrete can be kept at a temperature of t less than 45°F. for a period of 5 days after the concrete is placed.

85.63. Sufficient heating apparatus, such as stoves, salamanders, or am equipment, and fuel to furnish all required heat, shall be supplied. All ter using for mixing concrete shall be heated to a temperature of at least , but not over 150°F. Aggregates shall be heated either by steam or by y heat to a temperature of at least 70, but not over 150°F. The heating paratus shall be such as to heat the mass uniformly and preclude the ssibility of the occurrence of hot spots which will burn the material. The mperature of the mixed concrete shall not be less than 60°F. at the time placing in the forms.

85.64. The contractor shall assume all risk connected with the placing of ncrete during freezing weather, and permission given by the engineer to ace concrete during such time will in no way relieve the contractor of ponsibility for satisfactory results. Should concrete placed under such nditions prove unsatisfactory, it shall be rejected. It is understood that e contractor is responsible for the quality and strength of concrete placed der any and all weather conditions.

85.65. **Depositing in Water.**—Concrete shall be deposited in water only th the permission of the engineer and under his supervision. It shall be ass *A* concrete with 10% of excess cement. The cofferdams shall be fficiently tight to prevent any current passing through the space in which the ncrete is to be deposited. Pumping will not be permitted in the cofferdams ile the concrete is being placed, nor until it has reached its initial set.

85.66. When depositing in water is allowed, the concrete shall be carefully aced in the space in which it is to remain in a compact mass by means of a mie, closed-bottom dumping bucket, or other approved method that es not permit the concrete to fall through the water without adequate otection. The concrete shall not be disturbed after being deposited. concrete shall be placed in running water, and forms which are not asonably water-tight shall not be used for holding concrete deposited der water. Depositing shall be regulated to produce approximately rizontal surfaces.

85.67. When a tremie is used, it shall consist of a tube having a diameter of t less than 10″, constructed in sections having flanged couplings fitted with skets. The means of supporting the tremie shall be such as to permit the e movement of the discharge end over the entire top surface of the work d shall be such as to permit it to be rapidly lowered when necessary to oke off or retard the flow. The discharge end shall be entirely sealed at times and the tremie tube kept full to the bottom of the hopper. When batch is dumped into the hopper the tremie shall be slightly raised, but out of the concrete at the bottom, until the batch discharges to the tom of the hopper. The flow is then stopped by lowering the tremie. e flow shall be continuous and in no case shall be interrupted until the rk is complete.

35.68. When concrete is placed by means of a bottom-dump bucket, the cket shall have a capacity of not less than ½ cu. yd. The bucket shall lowered gradually and carefully until it rests upon the concrete already ced. It shall then be raised very slowly during the discharge travel, the ent being to maintain, as nearly as possible, still water at the point of charge and to avoid agitating the mixture.

35.69. **Rubble or Cyclopean Concrete.**—Rubble or cyclopean concrete ll consist of either Class *B* or Class *C* concrete, in which is imbedded large ividual stones in accordance with the following requirements:

35.70. This class of concrete shall be used only in massive piers, gravity itments, and heavy footings and only with the approval of the engineer.

35.71. The stone for this class of work shall be of the quality required coarse aggregate, and may be one-man stone or derrick stone as specified einbelow.

85.72. The stone shall be carefully placed (not dropped or cast) and tl method of placing shall be such as to avoid injury to the forms or to the parl ally set adjacent masonry. Stratified stone shall be placed upon its natur bed. All stone shall be thoroughly saturated with water before being place

85.73. The total volume of the stone used shall not be greater than on third of the total volume of the portion of the work in which it is placed.

85.74. For walls or piers greater than 2′ in thickness, one-man stone ma be used. Each stone shall be completely surrounded by a layer of concre not less than 6″ in thickness. No stone shall extend above a point 1′ belc the top surface of any wall or pier nor shall it extend within less than 8″ any coping.

85.75. For walls or piers greater than 4′ in thickness derrick stone may used. Each stone shall be completely surrounded by a layer of concre not less than 1′ in thickness. No stone shall extend above a point of below the top surface of any wall or pier nor shall it extend within less th 8″ of any coping.

85.76. **Concrete Exposed to Sea Water.**—For concrete exposed to t action of sea water, the following requirements shall govern:

85.77. Concrete for walls 2 feet or less in thickness shall be mixed in t proportions specified for Class *A* concrete with 10% additional cemei For mass walls, that portion of the surface exposed to the action of salt wat and for a distance of at least 2′ inward from the exterior of the mass shall constructed as above specified, while the interior of the mass may be cc structed of concrete as specified on the plans and mixed in the ordina manner. The original surface as the concrete comes from the forms sh be left undisturbed. In order to secure a thick and dense surface film, t form surfaces shall be heavily coated with shellac or an approved form (No construction joints shall be located between points 2′ below extreme l water and 4′ above extreme high water.

85.78. In general, reinforced concrete shall not be used in sea wat However, when it is used, the reinforcement shall be placed as far from t surface as is consistent with the design and shall be proportioned to withsta a stress of not more than three-fourths of the allowable stress. The mi mum clear distance from the face of the concrete to the nearest face of a reinforcing bar shall in no case be less than 5″ except in precast concr piles, where a 3″ minimum may be used.

85.79. Concrete exposed to the action of drift or to impact and abras from any cause shall be protected by encasing that portion of the surfa extending from an elevation at least 4′ above high tide to an elevation below low tide, with a special sheathing or protective armor as shown the plans or noted in the supplemental specifications, and provision shall made in the size of the original cofferdam for sufficient clearance to perr access to the masonry surface for the installation and effective anchorage this sheathing.

85.80. The protective armor above noted may be of metal plates, a vit fied brick, or dense stone facing, a dense mortar facing placed simultaneou with the interior of the wall by means of baffle plates, treated timber shea ing, or other approved construction.

85.81. When so specified, the cofferdam may be constructed above t mud line with treated material and left permanently in place. In this ca the space between the neat masonry lines and the interior of the cofferd shall be filled with waterproof material.

85.82. Concrete between the tide limits above specified shall not, in a case, be deposited in sea water. In no case shall fresh concrete within th limits be exposed to the action of sea water nor shall salt water be allowed come in contact with the concrete until it shall have been allowed to for at least 30 days and preferably for a longer period.

85.83. Concrete piles when used in alkali soils shall, unless otherw specified, be subject to the same requirements as are provided hereinabo for concrete piles in sea water.

85.84. **Concrete Exposed to Alkali Soils or Water.**—In general, the sa requirements as above specified for concrete in sea water shall govern t construction of concrete in alkali soils or water. When so specified, t forms below the ground line may be constructed of treated timber, wat proofed with a brush coating of a suitable bituminous material, and l permanently in place. In lieu of the above, the surface of the concr below ground may be treated with an approved system of membrane wat proofing or may be protected by a sheathing of suitable design. Concr shall not be allowed to come in contact with alkali soil or water until

ll have been allowed to set for at least 30 days and for a longer period if sible. No construction joints shall be permitted below an elevation of 2′ ve the ground line. The surface film shall be left intact as it comes from forms. To secure a heavy and dense surface film, the form surfaces ll be heavily coated with shellac or an approved form oil. The soil und footings placed in alkali soil shall be thoroughly and effectively ined to avoid a concentration of salts at or around the footings.

5.85. **Removal of Forms.**—In order to make possible the obtaining of a isfactory surface finish, forms on ornamental work, railings, parapets, l exposed vertical surfaces shall be removed in not less than 12 nor re than 48 hr., depending upon weather conditions. Forms shall always removed from columns before removing shoring from beneath beams or lers, in order to determine the condition of concrete in the columns.

5.86. The following table shall serve as a guide for the minimum time uired before the removal of forms, not counting the days in which the perature is below 40°F.:

Centering under beams	28 days
Floor slabs	14 to 28 days
Walls	7 days
Columns	10 days
The sides of beams, and all other parts	7 days

5.87. No forms whatever shall be removed at any time without the sent of the engineer. Such consent shall not relieve the contractor of onsibility for the safety of the work. As soon as the forms are removed bolts, wires, or other appliances which hold the forms and which pass ough the concrete shall be cut off or set back 1″ below the surface. All gh places, holes, and porous spots shall be filled with mortar composed part Portland cement to 2 parts sand.

5.88. **Defective Work.**—Any defective work discovered, after the forms e been removed, shall be removed immediately and renewed. If the ace of the concrete is bulged, uneven, or shows excess honeycombing or n marks, which in the opinion of the engineer cannot be repaired satis-orily, the entire section shall be removed and renewed, and no compen-on will be allowed for the work or material.

5.89. **Curing Concrete.**—Careful attention shall be given by the con-tor to the proper curing of concrete hand rails, floors, and finished sur-s. Such surfaces shall be protected from the sun and the whole structure l be kept wet for a period of at least 7 days. All concrete floors shall overed as soon as possible with sand, earth, or other suitable material kept thoroughly moistened for a period of at least 10 days by sprinkling morning and evening, or more frequently if deemed necessary by the neer. The covering material shall not be cleared from the surface of concrete floor for a period of at least 28 days.

.90. Unless otherwise permitted by the engineer, concrete bridge floors be closed to traffic for a period of at least 21 days after placing, and for additional time as it may be deemed advisable.

.91. **Finish.**—The external surface of concrete shall be given one of the wing finishes as required on plans:

.92. **Class 1. Surface Finish.**—As soon as the pointing has set suffi-ly to permit it, the entire surface shall be thoroughly wet with a brush rubbed with a No. 16 carborundum stone or an abrasive of equal quality, ging the surface to a paste. The rubbing shall be continued sufficiently move all form marks and projections, producing a smooth, dense surface out pits or irregularities.

.93. The material which, in the above process, has been ground to a e shall be carefully spread or brushed uniformly over the entire surface allowed to take a "reset." The final finish shall be obtained by a ough rubbing with a No. 30 carborundum stone or an abrasive of equal ty. This rubbing shall continue until the entire surface is of a smooth re and uniform in color.

.94. After the final rubbing is completed, the surface shall be thoroughly hed and kept wet for a period of 7 days, unless otherwise directed.

.95. Railing balusters and other precast members which have been ured by the drip from the abrasive shall be thoroughly cleaned by s of a dilute solution of muriatic acid.

.96. **Class 2. Surface Finish.**—After the pointing has set sufficiently rmit it, the entire surface shall be thoroughly wetted and rubbed with

a No. 16 carborundum stone or an abrasive of equal quality to bring surface to a smooth texture and remove all form marks. The paste for by the rubbing as above described may be finished by carefully strip with a clean brush, or it may be spread uniformly over the surface allowed to take a "reset," after which it may be finished by floating wi canvas, carpet-faced, or cork float or rubbed down with dry burlap.

85.97. **Treatment and Finish for Horizontal Surfaces Not Subjecte Wear.**—All upper horizontal surfaces such as the tops of hand-rail posts caps and the tops of parapets, copings, and bridge seats shall be forme placing an excess of material in the forms and removing or striking such excess with a wooden templet, forcing the coarse aggregate below mortar surface. The use of mortar topping for concrete railing caps other surfaces falling under this classification shall in no case be permitte

85.98. The final finish for caps and railings shall be obtained in one of following ways:

85.99. *a.* **Brush Finish.**—After the concrete has been struck off, as al described, the surface shall be thoroughly worked and floated with a woo canvas, or cork float, the operation to be performed by skilled and experie concrete finishers. Before this last finish has set, the surface shall be lig striped with a fine brush to remove the surface cement film, leaving a grained, smooth, but sanded texture.

85.100. *b.* **Float Finish.**—In lieu of the above, the surface may be fini with a rough carpet float or other suitable device, leaving the surface e but distinctly sandy or pebbled in texture.

85.101. *c.* **Ground or Terrazzo Finish.**—When specified, the upper face or rail caps, parapets, etc., may be finished by grinding with a carbo dum stone, or equally good abrasive, to a smooth, dense, terrazzo fi Finish of this character shall be done as follows:

85.102. Using a No. 16 carborundum stone or an abrasive of equal qua the surface shall be ground dry or in water until it is smooth and the ind ual pebbles and aggregate particles are cut and polished. The su shall then be completely cleansed with water, and the final rubbing by means of a No. 30 stone. The finished surface shall present the textu polished marble and shall show the various aggregate particles in poli outline.

85.103. *d.* **Other Types.**—Special types of rail cap finish, such as "t finish," "sand-blasted finish," etc., shall be done in accordance with general requirements governing Special Surface Finishes, as herein provided.

85.104. **Special Surface Finishes.**—When so specified, special su finishes may be employed for ornamental panels, coping, and like cons tion. In general, the method and manner of performing this work w fully provided for in the special provisions for the particular work in ques

85.105. In each case the contractor shall be required to prepare te sample panels under the direction of the engineer, and the method manner of finish, the choice and selection of the aggregate, and other fea affecting the work shall be approved before any further work is done.

85.106. Following are typical general requirements for the prin types of special surface finishes:

85.107. **Tooled Finish.**—Finish of this character for panels and othe work may be secured by the use of a bush hammer, pick, crandall, or approved tool. Air tools shall preferably be employed. No tooling be done until the concrete has set for at least 14 days and as much long may be necessary to prevent the aggregate particles from being "pic out of the surface. The finished surface shall show a grouping of br aggregate particles in a matrix of mortar, each aggregate particle bei slight relief.

85.108. **Sand-blast Finish.**—The type of finish required in this me shall be similar to that above described for tooled finish, but finer gr in texture. The sand blasting must be done by means of approved equip and in such manner as to produce an even, fine-grained surface in whic mortar has been cut away, leaving the aggregate particles exposed.

85.109. **Wire-brush or Scrubbed Finish.**—This type of finish sha produced by scrubbing the surface of a green concrete with stiff wire or brushes, using a solution of muriatic acid in the proportion of 1 part ac 4 parts water. As soon as the forms are removed and while the concr yet comparatively green, the surface shall be thoroughly and evenly scru as above described until the cement film or surface is completely rem and the aggregate particles are exposed, leaving an even-pebbled te

senting an appearance grading from that of fine granite to coarse conglomte, depending upon the size and grading of aggregate used. Granite ps or colored aggregates may be used in this connection if desired. As n as the scrubbing has progressed sufficiently to produce the texture ired, the entire surface shall be thoroughly washed with water, to which a ill amount of ammonia has been added, to remove all traces of the acid.

5.110. **Methods of Measurement.**—All concrete conforming to the specition and plans and placed as directed shall be measured by the cubic d in place. In computing the concrete yardage for payment, the dimenis used shall be those shown on plans or ordered in writing by the engineer. measurements or other allowances shall be made for work or material forms, falsework, cofferdams, pumping, bracing, etc. No deductions neasurement shall be made for paneling less than 6″ in width.

5.111. **Basis of Payment.**—Payment shall be made for the yardage of epted concrete measured as prescribed above at the contract unit price per cubic yard for Class *A*, Class *B*, Class *C*, or Class *D* concrete, as case may be. Such payment shall be full compensation for all materials, ns, falsework, placing, and finishing, all equipment, tools, labor, and dentals necessary to complete the item, except that steel reinforcement ll be paid for as a separate item.

Item 82. Steel Structures[1]

2.1. **Description.**—All steel structures shall be built as indicated on the ns, conforming to line, grade, dimensions, and design shown, and in ordance with the specifications for piling, concrete, masonry, structural l, and other pay items which are to constitute the complete structure, in conformity with such specifications prescribed under concrete bridges re involved.

2.2. **Materials and construction methods** used shall be those prescribed the several items which are to constitute the structure and in addition l conform to the following requirements:

Fabrication

2.3. All deformed structural material shall be properly straightened by hods which are non-injurious, prior to being laid off, punched, or otherwise ked in the shop. Sharp kinks and bends shall be cause for rejection.

2.4. The workmanship and finish shall be first class and equal to the best ctice in modern bridge shops. Shearing and chipping shall be neatly and rately done, and all portions of the work exposed to view shall be neatly hed. No changes shall be made in any drawing after it has been approved pt by the consent or direction of the engineer in writing. Substitutions ections having different dimensions from those shown on the plans shall nade only when approved in writing by the engineer.

2.5. **Rivet Holes.**—When general reaming is not required, holes in material or less in thickness may be punched full size. Holes in material more n ¾″ in thickness shall be subpunched and reamed, or drilled from the l.

2.6. **Punched Holes.**—Full-size punched holes shall be 1⁄16″ larger than nominal diameter of the rivet. The diameter of the die shall not exceed diameter of the punch by more than 3⁄32″. Holes must be clean cut, out torn or ragged edges. If any holes must be enlarged to admit the ts, they shall be reamed.

2.7. **Accuracy of Punched Holes.**—The punching of holes shall be so rately done that after assembling the component parts of a member, lindrical pin 1⁄8″ smaller than the nominal diameter of the punched hole be passed through at least 75 of any group of 100 contiguous holes in same surface or in like proportions for any group of holes. If this irement is not fulfilled, the badly punched pieces shall be rejected. ny holes will not pass a pin 3⁄16″ smaller than the nominal diameter of punched hole, this shall be cause for rejection.

2.8. **Drilled Holes.**—Drilled holes shall be 1⁄16″ larger than the nominal neter of the rivet. Burrs on the outside surfaces shall be removed with ol producing a 1⁄16″ fillet around the edge of the hole.

2.9. **Subpunched and Reamed Holes.**—Subpunched and reamed holes be punched 1⁄16″ smaller than the nominal diameter of the rivet and then be reamed to a diameter 1⁄16″ larger than the nominal diameter of

[1] Texas.

the rivet. The punch and die shall have the same relative sizes as spec for full-size punched holes. Burrs produced by reaming shall be remo with a tool producing a $\frac{1}{16}''$ fillet around the edge of the hole.

82.10. Reaming of rivet holes shall be done with twist drills or with s taper reamers. Reamers preferably shall not be directed by hand. oil or grease shall be used as a lubricant.

82.11. **Accuracy of Reamed and Drilled Holes.**—Reamed or drilled h shall be cylindrical and perpendicular to the member and their accuracy s be the same as specified for punched holes except that after reaming or dri 85 of any group of 100 contiguous holes in the same surface, or in like pro tion for any group of holes, shall not show an offset greater than $\frac{1}{32}''$ betw adjacent thicknesses of metal.

82.12. **Drifting of Holes.**—The drifting done during assembling shal only such as to bring the parts into position and not sufficient to enlarge holes or distort the metal.

82.13. **General Reaming.**—General reaming may be required, in w case a definite provision to this effect shall be included elsewhere in contract.

82.14. When general reaming is required, all rivet holes in main mem shall be subpunched and reamed or drilled from the solid. This requirer shall not apply to rivet holes in top and bottom chord lateral meml lateral hangers, truss and girder sway bracings, and to the lateral pla connection angles, etc., connecting these members to the main mer of the structure. Connection plates or other parts acting both as m member material and secondary (lateral sway bracing, etc.) member mat shall generally have subpunched and reamed holes in locations enga similar holes in main members.

82.15. Reaming shall be done after the pieces forming a built mer are assembled and firmly bolted together. No interchange of reamed p will be permitted.

82.16. **Field Connections.**—When general reaming is required, or in pun work when specifically required by the engineer, holes for field connect except those in lateral, longitudinal and sway bracing, shall be reame drilled. Riveted trusses shall be assembled in the shop; the parts adju to line and fit, and the holes for field connections reamed or drilled w so assembled. Holes for other field connections shall be reamed or dr with the connecting parts assembled, or else reamed or drilled to a m template not less than 1″ thick.

82.17. **Shop Assembling.**—All surfaces of metal to be in contact w assembled shall be carefully painted with one coat of the paint specifie the shop coat. The paint shall be applied upon surfaces free from loose mill scale, or other foreign matter and the parts shall be assem while the paint is plastic.

82.18. The component parts of a built member shall be assembled, pinned to prevent lateral movement, and firmly bolted to draw the p into close contact before reaming, drilling, or riveting is begun. Assem parts shall be taken apart, if necessary, for the removal of burrs and shav produced by the reaming operation.

82.19. The member shall be free from twists, bends, or other deformat

82.20. Preparatory to shop riveting full-size punched material, the r holes shall be cleared for the admission of the rivets by reaming.

82.21. End connection angles, stiffener angles, etc. shall be care adjusted to correct locations and rigidly bolted, clamped or otherwise fi held in place until riveted.

82.22. **Match Marking.**—Connecting parts assembled in the shop for purpose of reaming or drilling holes in field connections shall be match mar and a diagram showing such marks shall be furnished to the engineer.

82.23. **Rivets.**—The diameter of rivets indicated upon the plans sha understood to mean their diameter before heating.

82.24. Heads of driven rivets shall be of approved shape, concentric the shanks, true to size, full, neatly formed, free from fins, and in full con with the surface of the member.

82.25. **Field Rivets.**—Field rivets, for each size and length, shal supplied in excess of the actual number to be driven to provide for lo due to misuse, improper driving, or other contingencies. Rivets shal free from furnace scale on their shanks, and from fins on the under sid the machine-formed heads.

82.26. **Bolts and Bolted Connections.**—Bolted connections shall no used unless specifically authorized. Where bolted connections are permit

bolts furnished shall be unfinished bolts (ordinary rough or machine .s), or turned bolts, as specified or directed by the engineer.

2.27. **Unfinished Bolts.**—Unfinished bolts shall be standard bolts with agonal heads and nuts. The use of "button-head" bolts will not be nitted. Bolts transmitting shear shall be threaded to such a length ; not more than one thread will be within the grip of the metal. The s will be of lengths which will extend entirely through their nuts but not e than $\frac{1}{4}''$ beyond. The diameter of the bolt holes shall be $\frac{1}{16}''$ iter than the diameter of the bolts used.

2.28. **Turned Bolts.**—Holes for turned bolts shall be carefully reamed rilled and the bolts turned to a driving fit by being given a finishing cut. threads shall be entirely outside of the holes and the heads and nuts l be hexagonal. Approved nut locks shall be used on all bolts unless persion to the contrary is secured fom the engineer. When nut locks are not l, round washers having a thickness of $\frac{1}{8}''$ shall be placed under the nuts.

2.29. **Riveting.**—Rivets shall be heated uniformly to a light cherry red r and shall be driven while hot. The heating of the points of rivets e than the remainder will not be permitted. When ready for driving, shall be free from slag, scale, and other adhering matter, and when en, they shall completely fill the holes. Burned, burred, or otherwise ctive rivets, or rivets which throw off sparks when taken from the ace or forge, shall not be driven.

2.30. Loose, burned, badly formed or otherwise defective rivets shall be out. Calking and recupping of rivets heads will not be allowed. In ing out defective rivets, care shall be taken not to injure the adjacent al, and if necessary, the rivet shank shall be removed by drilling.

2.31. Countersinking shall be neatly done and countersunk rivets shall pletely fill the holes.

2.32. Shop rivets shall be driven by direct-acting riveters where practicable. riveting machine shall retain the pressure for a short time after the tting is complete.

2.33. Pneumatic hammers shall be used for field riveting except when the of other hand tools for riveting is permitted by the engineer.

2.34. **Edge Planing.**—Sheared edges of material more than $\frac{5}{8}''$ in thick- shall, when required by the engineer, be planed to a depth of not less 1 $\frac{1}{8}''$. Reentrant cuts shall be filleted before cutting.

2.35. **Planing of Bearing Surfaces.**—Ends of columns taking bearing n base and cap plates shall be milled to true surfaces and correct bevels r the main section of these members and the end connection angles e been fully riveted.

2.36. Caps and base plates of columns and the sole plates of girders and ses shall have full contact when assembled. The plates, if warped or rmed, shall be hot-straightened, planed, and otherwise treated to re an accurate, uniform contact. After being riveted in place, the ss metal of countersunk rivet heads shall be chipped smooth and flush 1 the surrounding metal and the surfaces which are to come in contact 1 other metal surfaces shall be planed or milled, if necessary, to secure er contact. Correspondingly, the surfaces of base and sole plates ch are to come in contact with masonry shall be rough finished, if not from warps or other deformations.

2.37. Surfaces of cast pedestals and shoes which are to come in contact 1 metal surfaces shall be planed and those which are to take bearing upon masonry shall be rough finished.

2.38. In planing the surfaces of expansion bearings, the cut of the tool l be in the direction of expansion.

2.39. Surfaces of bronze bearing plates intended for sliding contact shall arefully milled and polish finished.

2.40. **Abutting Joints.**—Abutting ends of compression members shall, r being riveted, be accurately faced to secure an even bearing when mbled in the structure.

2.41. Ends of tension members at splices shall be rough finished to secure e and neat but not contact-fitting joints.

2.42. **End Connection Angles.**—End connection angles of floor beams stringers shall be flush with each other and accurately set as to position length of member. In general, end connection angles shall not be hed unless required by the terms of the contract. However, faulty mbling and riveting may be cause for requiring them to be milled, in ch case their thickness shall be reduced not to exceed $\frac{1}{16}''$ nor shall their t-bearing value be reduced below design requirements.

82.43. Built Members.—The several pieces forming one built mem shall be straight and close fitting. Such members shall be true to deta dimensions and free from twists, bends, open joints, or other defects resul from faulty fabrication and workmanship.

82.44. Lacing Bars.—The ends of lacing bars shall be neatly roun unless otherwise indicated.

82.45. Web Plates.—Web plates of girders having no cover plates may detailed with the top edge of the web flush with the backs of the fla angles. Any portion of the plate projecting beyond the angles shall chipped flush with the backs of the angles. Web plates of girders hav cover plates may be ½″ less in width than the distance back to bacl flange angles.

82.46. When web plates are spliced not more than ⅜″ clearance betw ends of plates will be allowed.

82.47. Web Stiffeners.—End stiffener angles of girders and stiffener an intended as supports for concentrated loads shall be milled or grounc secure a uniform even bearing against the flange angles. Intermed stiffener angles shall fit sufficiently tight to exclude water after being pain

82.48. Web Splices and Fillers.—Web splice plates and fillers ur stiffeners shall fit within ⅛″ at each end.

82.49. Eyebars.—Eyebars shall be straight and true to size, and shal free from twists, folds in the neck or head, or any other defect affecting t service strength. Heads shall be made by upsetting, rolling, or forg Welds in the body portions or in the heads of bars will not be permit The form of the heads may be determined by the dies in use at the wo where the eyebars are to be made, if satisfactory to the engineer. thickness of head and neck shall not overrun more than 1⁄16″.

82.50. Boring.—Before boring, each eyebar shall be properly anne and carefully straightened. Pin holes shall be located on the center of the bar and in the centers of the heads. The holes in the ends of the shall be bored simultaneously and shall be so accurately located that w the bars of the same truss panels are placed in a pile, the pins may be c pletely inserted in the pin holes without driving. All eyebars intended the same location in the trusses shall be interchangeable.

82.51. Annealing.—All eyebars shall be annealed by heating unifor to the proper temperature followed by slow and uniform cooling in furnace. The temperature of the bars shall be under full control at all sta

82.52. Forged pins and other steel parts requiring their full strer which have been partially heated shall be subsequently annealed. Sl bends in pieces of secondary importance may be made without heating metal. Crimped web stiffeners need not be annealed.

82.53. Pins and Rollers.—Pins and rollers shall be accurately turne detailed dimensions and shall be smooth, straight, and free from flaws. final surface shall be produced by a finishing cut.

82.54. Forged Pins.—Pins having a diameter greater than 6″ shal forged and annealed.

82.55. Border Pins.—Pins larger than 8″ in diameter shall have a not less than 2″ in diameter bored longitudinally through their cent Pins showing defective interior conditions shall be rejected.

82.56. Boring Pin Holes.—Pin holes shall be bored true to detailed din sions, smooth, and straight; at right angles with the axis of the mem and parallel with each other unless otherwise required. A finishing shall always be made.

82.57. The length outside to outside of holes in tension members and in to inside of holes in compression members shall not vary from deta dimensions more than 1⁄32″. Boring of holes in built-up members shal done after the riveting is completed.

82.58. Pin Clearances.—The difference in diameter between the pin the pin hole shall be not more than 1⁄32″.

82.59. Welds.—Welding of steel shall not be permitted except to rem minor defects, and then only with the approval of the engineer.

82.60. Screw Threads.—Screw threads shall make close fits in the n and shall be U. S. Standard except that for diameters greater than 1 they shall be made with six threads to the inch.

82.61. Pilot and Driving Nuts.—Two pilot nuts and two driving n shall be furnished for each size of pin, unless otherwise specified.

Mill And Shop Inspection

82.62. Notice of Rolling and Fabrication.—The contractor shall g ample notice to the engineer of the beginning of work at the mill and sh

hat inspection may be provided. No material shall be rolled or fabri- ed before the engineer has been notified where the orders have been placed.

2.63. **Facilities for Inspection.**—The contractor shall furnish all facilities the inspection of material and workmanship in the mill and shop and ectors shall be allowed free access to the necessary parts of the premises.

2.64. **Inspector's Authority.**—The inspector shall have the power to ct materials or workmanship which do not fulfil the requirements of se specifications; but in cases of dispute the contractor may appeal to engineer, whose decision shall be final.

2.65. Inspection at the mill and shop is intended as a means of facilitat- the work and avoiding errors, and it is expressly understood that it will relieve the contractor from any responsibility in regard to imperfect erial or workmanship and the necessity for replacing same.

2.66. **Mill Orders and Shipping Statements.**—The contractor shall ish the engineer with as many copies of mill orders and shipping state- ts as the engineer may direct. The weights of the individual members l be shown.

2.67. **Cost of Testing.**—Unless otherwise provided, the contractor shall ish, without charge, test specimens as specified herein, and all labor, ing machines, and tools necessary to prepare the specimens and to make full-sized tests.

2.68. **Rejections.**—The acceptance of any material or finished members the inspector shall not be a bar to their subsequent rejection, if found ective. Rejected material and workmanship shall be replaced promptly nade good by the contractor.

2.69. **Marking and Shipping.**—Members weighing more than 3 tons shall e the weight marked thereon. Bolts and rivets of one length and diame- and loose nuts or washers of each size shall be packed separately. Pins, ll parts, and small packages of bolts, rivets, washers, and nuts shall be ped in boxes, crates, kegs, or barrels, but the gross weight of any package l not exceed 300 lb. A list and description of the contained material l be plainly marked on the outside of each shipping container.

2.70. The weight of all tools and erection material shall be kept separate.

2.71. Anchor bolts, washers, and other anchorage or grillage materials l be shipped to suit the requirements of the masonry construction.

2.72. **Loading and Unloading.**—The loading, transportation, unloading, piling of structural material shall be so conducted that the metal will be t clean and free from injury by rough handling.

Erection

2.73. **Field Inspection.**—All work of erection shall be subject to the ection of the engineer who shall be given all facilities required for a ough inspection of workmanship.

2.74. Material and workmanship not previously inspected will be ected after its delivery to the site of the work.

2.75. **Storage.**—All material shall be stored in such manner as to prevent rioration by rust or loss of minor parts. No material shall be piled so o rest upon the ground or in water, but must be placed on suitable skids latforms.

2.76. **Preparation of Bearing Area.**—Column bases, truss and girder estals, and shoes shall have a full and uniform bearing upon the sub- cture masonry. Masonry bearing plates shall not be placed upon the lge-seat areas of piers or abutments which are improperly formed or gular.

2.77. The shoes and pedestals of truss and girder spans, the bases of mns, and the center and end bearings of swing spans shall be rigidly and nanently located to correct alignments and elevations. Unless otherwise vided, they shall be placed on a layer of canvas and red lead applied as ows:

2.78. Thoroughly swab the top surfce of the bridge-seat bearing area red-lead paint and place upon it three layers of 12- to 14-oz. duck, each r being thoroughly swabbed on its top surface with red-lead paint. Place superstructure shoes or pedestals in position while the paint is plastic.

2.79. **Handling Members.**—The field assembling of the component ts of a structure shall involve the use of methods and appliances not likely produce injury by twisting, bending, or otherwise deforming the metal. member slightly bent or twisted shall be put in place until its defects corrected, and members seriously damaged in handling shall be rejected.

2.80. **Alignment.**—Before beginning the field riveting, the structure shall adjusted to correct grade and alignment and the elevation of panel points

(ends of floorbeams) properly regulated. For truss spans a slight ex camber will be permitted while the bottom chords are being riveted, but correct camber and relative elevations of panel points shall be secured be riveting the top chord joints, top lateral system and sway bra ing.

82.81. **Straightening Bent Materials.**—The straightening of bent edge plates, angles, and other shapes shall be done by methods not likel produce fracture or other injury. The metal shall not be heated u permitted by the engineer, in which case the heating shall not be to a hi temperature than that producing a dark cherry-red color. After hea the metal shall be cooled as slowly as possible.

82.82. Following the completion of the straightening of a bend or bu the surface of the metal shall be carefully inspected for evidence of incip or other fractures.

82.83. **Assembling and Riveting.**—All field connections and splices sha securely drift pinned and bolted before riveting. Important connect in trusses, girders, floor system, etc. shall have at least 50 % of the h filled. An ample number of drift pins shall be used to prevent slippin joints and splices.

82.84. The results obtained in the field assembling and riveting of members of a structure shall conform to the requirements for shop asseml and riveting. Field-driven rivets shall be inspected and accepted be being painted.

82.85. Field riveting shall be done before the falsework is removed u special permission to the contrary is given by the engineer.

82.86. Railings shall not be riveted until the falsework has been remo

82.87. **Adjustment of Pin Nuts.**—All nuts on pins shall be thorou tightened and the pins so located in the holes that the members shall take and even bearing upon them.

82.88. **Setting Anchor Bolts.**—Anchor-bolt holes shall be drilled in co locations perpendicularly to the plane of the bridge seat, and the anchor shall be set in Portland-cement mortar therein. The mortar shall consi one part cement to one part clean, fine-grained sand mixed sufficiently w flow freely.

82.89. Anchor bolts shall first be dropped into dry holes to assure proper fit after setting. They shall then be set as follows: Fill the about two-thirds full of mortar and by a uniform, even pressure or by blows with a hammer (flogging and ramming will not be permitted), forc bolt down until the mortar rises to the top of the hole and the anchor nut rests firmly against the metal shoe or pedestal. Remove all e mortar which may have flushed out of the hole to permit proper field pair of the metal surfaces.

82.90. The location of the anchor bolts in relation to the slotted hol expansion shoes shall be varied with the prevailing temperature. The on anchor bolts at the expansion end of spans shall permit the free mover of the span.

82.91. The holes may be drilled in accordance with the provisions of above-mentioned article or, if in concrete masonry, may be formed by insertion in the fresh concrete of oiled wooden plugs or metal pipe sle which are subsequently withdrawn after the concrete has partially set. W the holes are formed by the latter method, they shall be not less tha in diameter to allow for horizontal adjustment of the bolts.

82.92. In lieu of the above methods of placing, anchor bolts in conc masonry may be set to exact location in the concrete when it is placed. this case great care shall be exercised to insure the proper setting of the b and any inaccuracies which will be detrimental to the structures shal corrected by suitable means.

82.93. **Setting Bedplates.**—Bedplates preferably shall be set on a lay canvas and red lead as specified in these specifications. When bedp are set in Portland-cement mortar, no superstructure or other load sha placed thereon until this mortar has been allowed to set for a period c least 96 hr.

82.94. **Placing Superstructure.**—No superstructure load shall be pl upon finished piers or abutments until the engineer directs. In gener minimum time of 21 days shall be allowed for the hardening of the conc before any superstructure load is placed thereon.

82.95. **Tubular Steel Piers.**—The general requirements governing depths of foundations as above set forth shall govern in the case of tub steel piers except that steel tubes resting upon gravel foundation witl piling shall in no case be carried to a depth less than 8′ below the perma

f the stream and to such additional depth as may be necessary to elimi- all danger of undermining.

96. Tubular piers shall, in general, be sunk by the open-dredging process. means of compressed air. The cross-sectional area of each tube shall ufficient to provide the requisite bearing area and to provide spacing for the requisite number of piles, in case piles are used. After the tubes unk to the desired elevation, the bottom shall be sealed by means of con- deposited under water. After the seal has set sufficiently to permit, ubes shall be unwatered and the rest of the concrete deposited in the If the seal is to act in flexure against the hydrostatic head, the tubes be weighed sufficiently to develop the necessary downward reaction sufficient shear anchorage provided around the interior circumference of ube to transfer this weight into the seal concrete.

97. Metal tubes shall be painted two coats of an approved structural before being sunk, and the exposed portions shall be given an additional after erection.

98. Piles used in connection with tubular steel piers shall be driven tubes are sunk unless otherwise permitted by the engineer. When n after the tubes are in place, the piles may be driven by means of a ver, provided that one pile out of every group of ten or one for every shall be a long pile driven without a follower, such pile to be used as a pile to determine the necessary length for the rest of the group. After ong pile is driven to the required penetration as determined by the ng power formula, it shall be cut off to the required elevation.

99. If desired (and under written permission from the engineer), tubular piers may be sunk in large holes which previously have been dredged e purpose. In this case, piles may be driven in the dredged hole before ubes are placed, cut off to the desired elevation, bound in cluster form ired, and the tubes placed over them. If this procedure is followed, the vated hole around the piers shall be carefully backfilled.

.100. Filling material for tubular piers shall be either Class *A* or Class ncrete as specified, except the bottom seal which shall be as specified for ete deposited under water.

Painting—Materials and Composition

.101. *a*. Paints shall consist of pigments of the required fineness and position, ground to the desired consistency in raw or boiled linseed oil, hich shall be added additional oil, and a thinner, or drier, or both. igments, oils, thinners, and driers used shall be of the best quality, free adulterants of any kind, and shall comply with the requirements given v for these materials.

.102. *b*. All paint paste shall consist of the specified pigment or pig- s ground in linseed oil to the required consistency. The paste must be epared that it is uniform in composition and consistency, will not cake gregate in the retainers, and will easily break up in oil to form a smooth, rm paint of proper brushing consistency. The color, hiding power, and it per gallon when specified shall be the same or equal to the approved le.

.103. *c*. To prepare a paint so that it will have the required consistency drying properties for the use intended, the paste shall be mixed with ient linseed oil, turpentine, and drier to produce a paint having these erties. Unless otherwise specified, the exact quantity of linseed oil, entine, and drier required for this purpose shall be determined by the neer.

.104. *d*. Raw linseed oil used shall conform to the requirements of the T. M. Standard Specifications for Purity of Raw Linseed Oil from North rican Seed D1-15, with subsequent amendments and additions thereto.

.105. The boiled linseed oil used shall conform to the requirements of A.S.T.M. Standard Specifications for Purity of Boiled Linseed Oil North American Seed, D11-15, with subsequent amendments and tions thereto.

.106. Furthermore, if permitted, raw and boiled linseed oil of South rican seed shall meet the requirements of tentative specifications of T.M. DN-21T and D-78-21T.

.107. *e*. Drier shall be composed of turpentine, lead, and manganese s cooked in linseed oil. The proportion of lead shall be not less than times that of manganese. It shall contain no resin or varnish gums, not more than 70 % shall volatilize at 450°F. When flowed on metal

and allowed to dry, it shall produce an elastic film. The flash point not be lower than 95°F. when tested in an open cup-tester. When a m of 10 % of drier with 90 % pure raw linseed oil is flowed on a glass slab, is then held nearly vertical, and is kept at a temperature of 70°F., wit access of air, the coating shall dry throughout, neither sticky nor b in not over 10 hr.

82.108. *f.* Turpentine shall be the distillate commonly known as turpentine," or "spirits turpentine," which is distilled from pine oleo or the product secured from resinous wood by extraction with v solvents, by steam or by destructive distillation. Either or both of two products—gum spirits or wood turpentine—shall be furnished f when so specified.

82.109. The turpentine shall be clear and free from suspended matte water.

The color shall be "Standard" or better.

The specific gravity shall be not less than 0.862 nor more than 0.8 15.5°C.

The refractive index at 15.5°C. shall be not less than 1.468 nor more 1.478.

The initial boiling point shall be not less than 150 nor more than 1 Ninety per cent of the turpentine shall distill below 170°C.

The polymerization residue shall not exceed 2 %, and its refractive at 15.5°C. shall be not less than 1.500.

82.110. *g.* **Pure White Lead. Dry Pigment.**—The pigment shall pure basic carbonate of lead of the formula $2PbCO_3PbOH_2$, containi to 75 % of lead carbonate, and shall conform to the requirements of ten specifications A.S.T.M. D81-21T and subsequent revisions, and not than 2 % of total impurities, including moisture. It shall be ground t fineness that it will all pass a 200-mesh sieve and contain not more tha material retained on a 325-mesh sieve.

82.111. Paste.—The paste shall be the dry pigment ground in pur linseed oil in the manner specified above. It shall consist of:

	Percentages Minimum	Percentages Maximum
Pigment	90	92
Linseed oil	8	10
Moisture and other volatile matter		0.7
Coarse particles and "skins" (total residue retained on a 200-mesh sieve, based on pigment)		2.0

82.112. Ready-mixed Paint.—The ready-mixed paint shall be pre from the paste in the manner specified above.

82.113. *h.* **Pure Zinc-oxide Paint. Dry Pigment.**—The dry pi shall consist of pure oxide of zinc which shall contain not less than 9 zinc oxide, nor more than two-tenths of 1% of sulphur or 2% of total in ties including moisture. The pigment shall be so ground that it will al a 200-mesh sieve.

82.114. Paste.—The paste shall be the dry pigment ground in oil as specified. It shall consist of:

	Percentages Minimum	Percentages Maximum
Pigment	82	86
Linseed	14	18
Coarse particles and "skins" (total residue left on a 200-mesh sieve, based on pigment)		0.5
Moisture and other volatile matter		0.5

82.115. Ready-mixed Paint.—The ready-mixed paint shall be pre from the paste in the manner specified above, in accordance with ten specifications of A.S.T.M. 79-21S.

82.116. *i.* **Red Lead. Dry Pigment.**—The dry pigment shall c entirely of the oxides of lead which shall conform to the requireme A.S.T.M. Specifications D-83-21T 95% grade.

82.117. Paste.—The paste shall be the pigment ground in oil as specified. It shall consist of:

	Percentages Minimum	Maximum
Pigment	92	95 or more
Linseed oil	6	8
Moisture and other volatile matter		0.5
Coarse particles and "skins" (total residue left on a 200-mesh sieve)		0.5

.118. **Ready-mixed Paint.**—The ready-mixed paint shall be prepared the paste in the manner specified above.

.119. The resulting paint, when mixed in the proportions given below brushed on a smooth vertical metal surface, shall dry hard and elastic out running, streaking or sagging.

.120. For Shop Coat.

Red-lead paste	20 lb.
Raw linseed oil	4½ pints (0.43 lb.)
Turpentine	2 gills (7.3 oz.)
Liquid drier	2 gills (12.0 oz.)

.121. The formula given above will produce 1 gal. of paint and should h 25 lb. and 10 oz.

.122. *j.* **Leaded Zinc Oxide. Dry Pigment.**—The dry pigment shall pure zinc oxide and a normal or basic lead sulphate. The pigment be so ground that it will all pass a 200-mesh sieve and the zinc oxide not contain more than 1 % of soluble salts nor more than 1.5% of total rities including moisture.

.123. This type of paint shall be divided into two brands, "high leaded" "low leaded." The high-leaded paint shall contain not less than 60% nc oxide and the low-leaded paint not less than 93% of zinc oxide, the ining pigment in each case to be a normal or basic lead sulphate.

.124. **Paste.**—The paste shall be the dry pigment ground in oil as above fied. It shall consist of:

	Percentages Minimum	Maximum
Pigment		88.0
Linseed oil	12.0	
Moisture and other volatile matter		0.5
Coarse particles and "skins" (total residue left on a 200-mesh sieve, based on pigment)		0.5

.125. **Ready-mixed Paint.**—The ready-mixed paint shall be prepared the paste in the manner specified above.

.126. *k.* **Sublimed Blue Lead.**—The sublimed blue lead pigment consist of sublimed blue lead fume, free from all adulterants and shall the following requirements:

	%
Lead sulphate (PbSO)	45–55
Lead oxide (PbO)	30–40
Lead sulphide (PbS)	Not over 12
Lead sulphite ($PbSO_3$)	Not over 5
Zinc oxide (ZnO)	Not over 5
Carbon and undetermined	Not over 5

127. Sublimed blue lead paint shall consist of either:
Sublimed blue lead in oil paste (90% sublimed blue lead ground in 10% inseed oil) mixed as follows:

100 lb. sublimed blue lead in oil paste
4 gal. pure raw linseed oil
2 pt. turpentine
2 pt. drier
} For field coat.

128. 2. A ready-mixed paint made by grinding pure dry sublimed lead in pure raw linseed oil in the following proportions:

90 lb. dry sublimed blue lead
5⅓ gal. raw linseed oil
2 pt. turpentine
2 pt. drier
} For field coat.

82.129. 1. **Graphite. Dry Pigment.**—The dry pigment shall be a amorphous and silicate rock to which may be added a small percenta carbon black, iron oxide, or other oxides needed to secure a desired tir color. The pigment shall be so ground that it will all pass a 200-mesh s and contain not more than 3 % of material retained on a 325-mesh si The prepared pigment must contain not less than 35 % nor more than of graphite in the form of graphitic carbon.

82.130. **Paste.**—The paste shall be the pigment ground in oil as a specified. It shall consist of:

	Percentages Minimum	Maxi
Pigment	62	6
Linseed oil	34	3
Moisture and other volatile matter		8
Coarse particles and "skins" (total per cent on a 325-mesh sieve, based on the pigment)	3	

82.131. **Ready-mixed Paint.**—The ready-mixed paint shall be pre from the paste in the manner above.

82.132. The resulting paint when mixed in the proportions given b and brushed on a smooth vertical metal surface shall dry hard and el without running, streaking, or sagging. It shall consist of:

	Percentages Minimum	Maxi
Pigment	30	3
Boiled linseed oil	65	7
Drier	5	
Turpentine and volatile matter	3	

82.133. All paints or paint materials shall be shipped in strong, subst containers, plainly marked with the name, color, and weight of paint co and name and address of the manufacturer.

82.134. *n.* **Manufacturer's Guarantee.**—The manufacturer of each l of paint submitted for acceptance under these specifications shall file the commission a certificate of analysis and manufacturer's guar setting forth the trade name or brand of paint to be furnished together w facsimile copy thereof and a typical analysis showing the percenta each of the chemical elements in the pigment vehicle. The manufact shall provide that all paint furnished under these specifications shall co to the certified analysis as filed and to the statement of the various per ages of the ingredients on the receptacle or container. The manufact guarantee shall be of the form furnished by the purchaser, and shall be s to by a person having legal authority to bind the company by his acts.

82.135. *o.* **Sampling and Testing.**—Samples when required for t purposes shall not be less than 1 qt. in amount. The paint shall be oughly stirred before selecting the sample.

82.136. In testing paint used under these specifications, the followin

1. Per cent of water in paint vehicle. Determination of water with reagent.
2. Raw linseed oil. Methods of testing prescribed in A.S.T.M. Sta Specification for Purity of Raw Linseed Oil from North American Seed D and for South American Seed A.S.T.M. D-77-21T D78-21T.
3. Boiled linseed oil. Methods of testing prescribed in A.S. Standard Specification for Purity of Boiled Linseed Oil from North Ame Seed D-11-15, and for South American Seed A.S.T.M. D-77-21T D78
4. Determination of volatile oils in vehicle. Bureau of Standards *Pub.* 15, p. 40.
5. Paint vehicle. Methods in Bureau of Standards, *Circular* 89.
6. Red lead. A.S.T.M. Standard Methods Routine Analysis Dry D-49-18.
7. White lead. A.S.T.M. Standard Methods Routine Analys White Pigments D34-17.
8. Sublimed blue lead. Shall be made in accordance with meth analysis of paint materials, subcommittee viii, A.S.T.M., Vol. 22, P and subsequent revisions thereto adopted by the society.
9. Zinc oxide. A.S.T.M. Standard Method of Routine Analy White Pigments D34-17.

Graphite pigment. Methods of tests prescribed in *Bulletin* 1216
. Dept. of Agr.).

137. *p*. No sieve is to be used in the determination of the fineness of the ents for these paints which on examination under a 150 magnification n a microscope shows any irregularity of wire spacings in the mesh or s any noticeable amount of wear on the sides of the wires.

138. **Standard 325-mesh Sieve.**—The 325-mesh sieve referred to in this fication is a woven rectangular-mesh wire sieve having not less than 322 nore than 327 meshes per linear inch in either direction. The nominal of opening shall be 0.0017″ square and the size of wire shall be 0.0014″ meter.

139. *q*. **Inspection.**—The contractor for these paints shall allow the inspector free access to all parts of his shops while work on these paints ng carried out; also the contractor shall give the inspector every reason- facility to enable him to insure that these paints are being made in dance with this specification.

140. *r*. Samples.—Before work is commenced on the manufacture of paints, the contractor shall furnish the state inspector with separate les of all pigments and vehicles to be used in such paints; each such le to be clearly labeled and marked to show the name of the material he name and number of the paint in which it is to be used. When so sted, samples and analyses of all pigments, oils, thinners, or driers or paints furnished shall be supplied by the manufacturer within 10 after request is made therefor. Before paint is shipped, the inspector take individual samples from one barrel in each five for each kind of . Tests may be made on individual samples or on one composite le for each 25 barrels of paint.

141. *s*. Paints which on analysis show more than a 3% variation in the rtion of any pigments or vehicle from that called for will be rejected.

Painting—Application

142. *a*. The painting of metal structures shall include, unless otherwise ded in the contract, the proper preparation of the metal surfaces, the cation, protecting, and drying of the paint coatings, the protection of trian, vehicular, or other traffic upon or underneath the bridge ure, the protection of all positions of the structure (superstructure and ucture) against disfiguremen by spatters, splashes and smirches of or of paint materials, and the supplying of all tools, tackle, scaffolding, workmanship, and materials necessary for the entire work.

143. *b*. **Number of Coats.**—All new structural-steel work shall, unless wise especially provided upon the plans or in the contract, be painted coats of paint. The first coat is to be applied immediately after the fabrication is complete except that all surfaces coming into contact be painted before being assembled. The second and third coats are applied after all erection is complete, except that immediately following eld riveting of the members, the heads of field rivets, and all abrasions shop coat due to handling at the shop, shipment, erection, etc., and all rection marks shall be thoroughly covered with one coat of shop paint ermitted to become thoroughly dry before the first field coat is applied.

144. *c*. The color of each succeeding coat shall be sufficiently different that previously applied to permit readily the discovery of an incomplete ation of the paint coat. The colors of the coats shall be determined e engineer.

145. *d*. **Weather Conditions.**—Paint shall be applied only when the mperature is at or above 40°F. It shall not be applied upon damp es or upon metal containing frost, nor shall it be applied when the misty, or otherwise, in the opinion of the engineer, unsatisfactory e work.

146. Material painted under cover in damp or cold weather shall n under cover until dry or until weather conditions permit its exposure open. Painting in open yards or upon erected structures shall not ne when the metal has absorbed sufficient heat to cause the paint to and produce a porous paint film.

147. *e*. **Application.**—No wide brushes shall be used. All brushes shall l in shape.

148. The paint when applied shall be so manipulated under the brush produce a uniform, even coating in close contact with the metal or previously applied paint. In general, the primary movement of the shall describe a series of small circles thoroughly to fill all irregularities

in the surface, after which the coating shall be smoothed and thinned series of parallel strokes.

82.149. To secure a maximum thickness of paint film upon rivet h edges of plates, angles, or other rolled shapes, these areas shall be "stri in advance of the general painting, and shortly afterward shall be gi second or "wash" coat when the general coat is applied. The paint be well worked into all joints and open spaces.

82.150. Paint shall be thoroughly stirred, preferably by means of mec cal mixers, before being removed from the containers, and to keep the ments in suspension shall be kept stirred while being applied.

82.151. All painting must be done in a neat and workmanlike ma On all surfaces which are inaccessible for paint brushes, the paint sh applied with sheep-skin daubers specially constructed for the purpose

82.152. *f.* **Removal of Improper Paint.**—All metal coated with imp unauthorized paint shall be thoroughly cleaned and repainted to the faction of the engineer, at the expense of the contractor.

82.153. *g.* **Thinning.**—If it is necessary in cool weather to thin the in order that it shall spread more freely, this shall be done only by he in hot water or on steam radiators.

82.154. *h.* **Shop Cleaning.**—All surfaces of metal to be painted sh thoroughly cleaned from rust, loose mill scale, dirt, oil or grease, ar other foreign substances. The removal of rust, scale, and dirt shall gen be done by the use of sand blast, metal brushes, scrapers, chisels, ham or other effective means. Oil and grease may be removed by the gasoline or benzine. Bristle or wood fiber brushes shall be used for rem loose dust.

82.155. *i.* **Shop Painting.**—In shop-riveted work, all surfaces co into contact when shop assembled shall each be painted a good sho thoroughly and evenly applied before assembling. These pieces m assembled while the paint is still wet.

82.156. When all fabrication work is complete and has been accept such, all surfaces not painted before assembling shall be painted a good coat. Shipping pieces shall not be loaded for shipment until thoro dry. No painting shall be done after loading material on cars.

82.157. *j.* Erection marks for the field identification of members sh painted upon previously painted surfaces.

82.158. *k.* With the exception of abutting chord and column s column and truss shoe bases, machine-finished surfaces shall be coa soon as practicable after being accepted, with a hot mixture of whit and tallow before removed from the shop. Surfaces of iron and castings milled for the purpose of removing scales, scabs, fins, bliste other surface deformations shall generally be given the shop coat of pa

82.159. The composition used for coating machine-finished surfaces be mixed in the following proportions:

4 lb. pure tallow.
2 lb. pure white lead.
1 qt. pure linseed oil.

82.160. *l.* **Field Cleaning.**—When the erection work is complete, incl all riveting, straightening of bent metal, etc., all adhering rust, scale grease, or other foreign matter shall be removed as specified under cleaning.

82.161. *m.* **Field Painting.**—As soon as the field cleaning is done satisfaction of the engineer, the heads of field rivets and any surfaces which the shop coat of paint has become worn off or has otherwise b defective and all shipping and erection marks shall be thoroughly co with one coat of the same paint as used in the shop and permitted to b thoroughly dry before the first field coat is applied.

82.162. When the paint applied for "touching up" rivet heads and ab surfaces has become thoroughly dry, the first and second field coats m applied. In no case shall a succeeding coat be applied until the pr coat has dried throughout the full thickness of the paint film.

82.163. All small cracks and cavities which have not become seale water-tight manner by the first field coat shall be filled with a pasty m of red lead and linseed oil before the second field coat is applied.

82.164. *n.* **Scope of Work.**—Unless otherwise provided, mainte painting shall consist of the removal of the rust, scale, dead paint grease, or other foreign matter from the metal parts or portions of ex bridge structures and the application of paint thereon.

165. All metal surfaces not in close contact with other metal surfaces th wooden floor or truss members, concrete, stone masonry, etc. shall nsidered as exposed to deterioration by rusting and shall be thoroughly ed and painted the number of coats indicated in and made a part of the act.

166. *o.* **Number of Coats.**—Unless otherwise provided, metal after cleaned to the satisfaction of the engineer, shall be painted with at two coats of paint.

167. *p.* **Cleaning and Painting.**—The requirements and methods of dure for maintenance, cleaning, and painting shall be the same as ied for shop and field painting.

168. Whenever roadway or sidewalk planking is laid too closely in ct with the metal to permit free access for proper cleaning and painting, anks shall either be removed or shall be cut to provide at least a 1″ nce for that purpose. The removal or the cutting of planks shall be as directed by the engineer. All planks removed shall be satisfactorily ed and if broken or otherwise injured to an extent rendering them unfit e, they shall be renewed at the expense of the contractor.

Design Details

169. In general, plans for steel bridges will not be approved except for ures spanning navigable channels, and for locations where the cost of ete structures would be prohibitive.

170. **Drawings.**—The state highway engineer will furnish designs, ng details preferred with usual conditions.

171. **Alternate Designs.**—Bidders may submit alternate designs when ble to the state highway engineer, and when so provided for in the to contractors. Alternate designs shall have as great strength and l merits as the designs furnished by the state highway engineer. rs submitting alternate designs shall furnish stress sheets and general which shall show all dimensions and sectional area.

172. **Size of Drawings.**—All drawings shall be 22 by 36″ over all, with gin of 2″ on the left-hand edge and ½″ margins on the other edges.

173. **Approval of Drawings.**—Upon the acceptance and execution of ntract, the contractor shall prepare and furnish standard-size working ngs showing complete details of all parts of the structure. Blueprints, plicate, of these drawings shall be submitted to the state highway eer for his approval before any material is ordered or work begun in op. All details shall be subject to his modifications or approval.

174. The contractor alone shall be responsible for the correctness of awing, although the drawing may have been approved by the engineer.

175. **Prints for the State Highway Department.**—After drawings have approved, the contractor shall furnish the state highway department, at cost, five complete sets of prints and four sets of all shipping bills.

176. **Name Plates.**—When specified one or more cast-iron name plates approved design, giving the date of construction, the names of the highway engineer, state bridge engineer, consulting bridge engineer, engineer, county commissioners court, and the contractor for the tructure, shall be securely bolted to the superstructure at the point nts specified.

177. **Width of Roadway and Sidewalk.**—The width of roadway shall clear width measured at right angles to the longitudinal center line bridge between the tops of curbs or guard timbers, if these exist; vise, it shall be the clear width inside to inside of the handrails or other ike protections paralleling the sides of the structure.

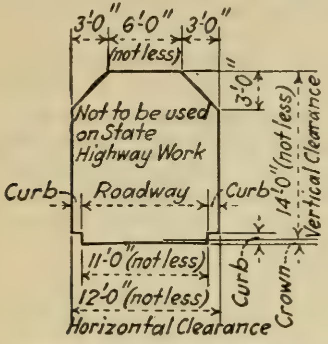
178. Upon structures having a sidewalk, the clear width of sidewalk e measured at right angles to the curb or guard timber and from the hereof to the extreme inside portion of the handrail. For structures trusses, girders, or parapet walls adjacent to the curbs, the width of lk shall be measured from their extreme outside portions to the inside handrail.

179. **Curbs.**—The width of curbs shall be not less than 6″ and pref- shall be not less than 9″. Their heights shall be not less than 9″.

180. **Clearances.**—The clearance width shall be the clear width avail- and the clearance height shall be the clear height available for the e of vehicular traffic as shown on the clearance diagrams.

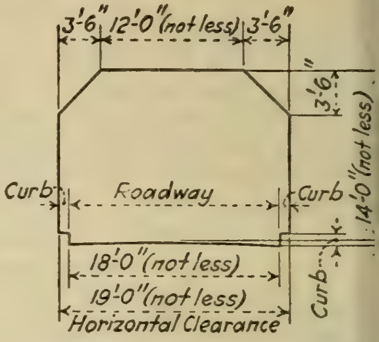
181. Unless otherwise provided, the several parts of the structure shall structed to secure the following limiting dimensions or clearances for

82.182. Bridges constructed for the use of one-way highway traffic have a roadway clearance not less than that shown in the diagram, F The roadway clearance for the use of two-way traffic shall be not less that shown in Fig. 2. The roadway width shall be increased at le for each additional line of traffic.



ONE WAY HIGHWAY TRAFFIC

FIG. 1.



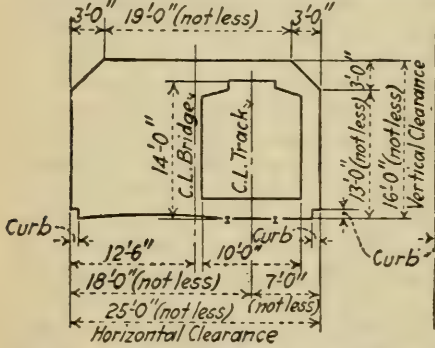
TWO WAY HIGHWAY TRAFFIC

FIG. 2.

Clearance diagrams.

82.183. Bridges constructed for the combined use of highway and ele railway traffic shall have roadway clearances not less than those sho Figs. 3 and 4.

82.184. In all cases involving curved tracks, the lateral clearances be increased an amount corresponding to that required to maintai



SINGLE TRACK RAILWAY AND ONE WAY HIGHWAY TRAFFIC

FIG. 3.

ELECTRIC RAILWAY AND TWO WAY HIGHWAY T

FIG. 4.

Clearance diagrams.

standard clearances. When the outer rail is superelevated, the clea shall be correspondingly increased.

82.185. **Spacing of Trusses and Girders.**—Main trusses and girders be spaced a sufficient distance apart center to center to be secure a overturning by the assumed lateral and other forces.

82.186. **Types of Bridges.**—The type of bridge to be used for v span lengths may be as follows:

Rolled beams up to 40′.
Plate girders from 30 to 100′.
Low riveted trusses from 45 to 100′.
Riveted trusses from 90 to 150′.
Riveted or pin-connected trusses above 150′.

2.187. *b.* **Loads.**—Unless otherwise provided, the component parts of a cture shall be proportioned for the stresses produced by the following ls with the assumed load distribution herein elsewhere prescribed. The sses due to each shall be shown separately upon stress sheets.

2.188. **Dead Load.**—The dead load shall consist of the weight of the cture complete, including the weight of the roadway floor, conduits, es, or other public-utility services supported thereon.

2.189. The following weights are to be used in computing the dead load:

Substance	Weight per Cubic Foot, Pounds
Steel	490
Iron, cast	450
Bronze	524
Timber (treated or untreated)	60
Concrete	144
Loose sand and earth	100
Rammed sand or gravel	120
Macadam or gravel rolled	140
Cinder filling	60
Asphalt wearing surface	150
Granite-block paving	160
Vitrified-brick paving	150
Granolithic pavement	150

.190. **Live Load.**—The integral parts of bridge floor systems, including direct connections to trusses, girders, and viaduct towers and bents, be designed for the maximum stresses produced by truck concentrations

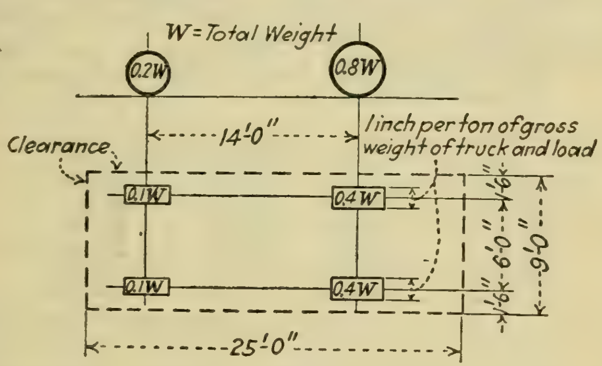


FIG. 5.—Typical truck loading.

beams, hangers, and all integral members or parts of trusses and rs subjected to the direct action of floor loads and impacts shall correndingly be designed for truck concentrations. The truck dimensions weight distributions used for design purposes shall be those of the al or standard trucks shown in Fig. 5. These standard trucks are nated by the letter H, followed by a numeral indicating for each class oss or total weight in tons.

191. The class of loading used shall be one of the following:

Loading H15	15-ton trucks.
Loading H10	10-ton trucks.

e Load for Trusses and Girders.—The trusses and girders of bridge spans he columns of viaduct towers and bents shall be designed for the stresses ced by a load on each traffic lane composed of a uniform load per foot of lane with a concentrated load so located longitudinally therein produce maximum stresses. The concentrated load shall be considered

as uniformly distributed transversely on a line having a length equal to t width of the lane. The standard truck clearance width of 9′ shall be assum as constituting the width of one traffic lane.

82.192. The class of loading used shall be one of the following:

Loading H15. A total load on each traffic lane composed of a unifo load of 450 lb. per linear foot and a single concentrat load of 21,000 lb.

Loading H10. A total load on each traffic lane composed of a unifo load of 300 lb. per linear foot and a single concentrat load of 14,000 lb.

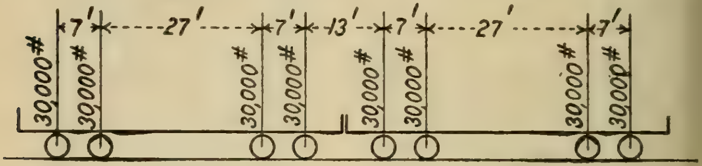


Fig. 6.—Electric car loading.

82.193. Load Classification of Bridges.—Bridges shall be classified rated in relation to their capacities for safely supporting highway loads. general, the division into classes and the corresponding loadings shall as follows:

Class *A*. Bridges supporting normally heavy highway-traffic units v occasional specially heavy loads. Class *A* bridges s be designed for loading H15.

Class *B*. Bridges of a temporary or semitemporary nature suppor light highway-traffic units. Class *B* bridges shall designed for loading H10.

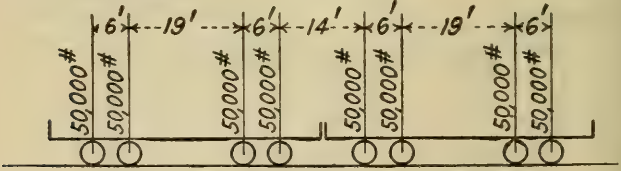


Fig. 7.—Freight car loading.

82.194. Application of Loads to Girders and Trusses.—Girders and tr shall be designed to support as many traffic lanes as the width of road will permit, assuming them to be placed symmetrically with regard to roadway center lines.

82.195. To provide for an increase in truss and girder stresses resul from the passage of eccentrically placed loads and for a decrease in tr lane intensity for increasing widths of roadway, the stresses obtained by application of the above loading shall be multiplied by the coefficie given by the following formulas:

Case I. When W is less than 18′,

$$C = \frac{W}{9}$$

Case II. When W is equal to or greater than 18′,

$$C = \frac{18 + W}{18n}$$

where W = the width of roadway for bridges with two main girder trusses; or the distance center to center of girders or tr for bridges with more than two main girders or trusses.

n = number of lanes of traffic.

2.196. **Application of Loads to Floor System.**—Bridge floor systems shall designed to support as many trucks, not exceeding four, as the width of dway will permit.

2.197. When the design of the floor system involves the placing of trucks acent to curbs, the extreme position of a truck shall be assumed as that which the center of the outside wheel is 1′ 6″ from the inside edge of the b.

2.198. **Sidewalk Loads.**—All sidewalk stringers and brackets shall be igned to support a live load of not less than 100 lb. per square foot of ewalk area.

2.199. Girders or trusses supporting sidewalks shall be designed to port a sidewalk live load as determined by the following formula, provided t in no case shall the live load be less than 20 lb. per square foot of sidewalk a:

$$P = (80 - 0.125L)(1 - 0.025W)$$

ere P = live load, in pounds per square foot of sidewalk area.
L = loaded length of sidewalk, in feet.
W = clear width of widewalk, in feet.

impact increment shall be added to sidewalk load.

2.200. In general, provision shall be made to prevent the encroachment roadway loads upon the sidewalk area. Whenever the details of the icture permit such encroachment, the sidewalks shall be designed for the dway loads and impacts so involved.

2.201. All live-load stresses, except those due to sidewalk loads and cenugal tractive and wind forces, shall be increased by an allowance for amic, vibratory, and impact effects.

2.202. For end floorbeams, floorbeam hangers, columns supporting rbeam concentrations and all floorbeam connections, the impact allowe shall be 60% of the live-load stress.

2.203. For all other portions of structures, the impact allowance or rement is expressed as a coefficient of the live-load stress varying with the ded length of the structure and the width of the roadway area. Its nsity is determined by the following formulas in which

I = impact coefficient.
L = loaded length in feet producing the maximum static stress in the member considered.
W = the width of roadway for bridges with two main girders or trusses; or the distance center to center of girders or trusses for bridges with more than two main girders or trusses.

or electric railway loads:

$$I = \frac{L + 900}{12L + 1200}$$

2.204. **For Highway Loads.**

Vhen W is equal to or less than 18′.

$$I = \frac{L + 250}{10L + 250}$$

Vhen W is greater than 18′,

$$I = \frac{36}{W + 18} \times \frac{(L + 250)}{(10L + 500)}$$

2.205. For highway loads, the maximum value of I, as given by the above nulas, shall not exceed 0.30. The impact allowance for intermediate r beams and stringers shall be 0.30.

2.205a. **Wind Load.**—The force due to wind and lateral vibrations shall aken as horizontal and shall be treated as a uniformly moving load acting y on the lateral and sway bracing. This lateral force shall be taken 0 lb. per square foot on one and one-half times the side area of all trusses irders plus the area of the railings and the vertical projection of the floor. the case of truss spans it shall be considered as divided between the led and the unloaded chords in the proportion of two-thirds to the ner and one-third to the latter. In addition to the foregoing, a moving l of 150 lb. per linear foot shall be considered as acting in the plane of the lge floor on highway bridges and 300 lb. per linear foot upon bridges for ibined highway and electric-railway service. However, in the case of ictures having a reinforced-concrete floor slab engaging the flanges of the l floor members this additional loaded chord load need not be considered.

82.206. *c.* **Distribution of Truck Wheel Loads to Stringers and Floo beams.**—In calculating end shears and end reactions of stringers and floc beams, no lateral or longitudinal distribution of wheel loads shall be assume

82.207. **Bending Moments.**—In determining bending moments in stringe: each wheel load shall be assumed as concentrated at a point. When t floor system is designed for one truck, each interior stringer shall be pı portioned to support that part of one rear wheel load, or those parts of o front wheel load and one rear wheel load, represented by a fraction whc numerator is the stringer spacing in feet and whose denominator is:

4′ 0″ for plank floors.

5′ 0″ for strip floors 4″ or more in thickness and for wood blocks on a plank subfloor.

6′ 0″ for reinforced-concrete floors.

82.208. When the floor system is designed for two trucks, each inter: stringer shall be proportioned to support that part of one rear wheel loa or these parts of one front wheel load and one rear wheel load, represent by a fraction whose numerator is the stringer spacing in feet and whc denominator is:

3′ 6″ for plank floors.

4′ 0″ for strip floors 4″ or more in thickness and for wood blocks on plank subfloor.

4′ 6″ for reinforced-concrete floors.

82.209. The live load supported by the outside stringers shall be t reaction of the truck wheels in the most unfavorable position, assuming t flooring to act as a simple beam, but this live load shall in no case be l than would be required for interior stringers under the above requiremer

82.210. The above distribution rules govern only when the stringer sp ing is not greater than the denominator which applies to the particular c: under consideration. When the stringer spacing is greater than this c tance, the stringer loads shall be determined by the reactions of the trı wheels placed in the most unfavorable position, assuming the flooring betwe stringers to act as simple beams.

82.211. The combined load capacity of the stringers in a panel shall be : less than the total live and dead load in the panel.

82.212. **Bending Moments in Floorbeams.**—In determining bend moments in floorbeams, each wheel load shall be assumed as concentratec a point.

82.213. When stringers are omitted and the floor is supported directly the floorbeams, the latter shall be proportioned to carry that fraction of axle load, when the floor system is designed for one truck, or of two a loads, when the floor system is designed for two trucks, whose numera is the floorbeam spacing in feet and whose denominator is:

4′ 0″ for plank floors.

5′ 0″ for strip floors 4″ or more in thickness and for wood blocks on 4″ pla subfloor.

6′ 0″ for reinforced-concrete floors.

82.214. When the spacing of floorbeams exceeds the denominator gi but is less than the axle spacing (14′ 0″), each beam shall be proportioı to carry the full axle load or loads.

82.215. When the floorbeam spacing exceeds the spacing of axles the l supported on each floorbeam shall be the maximum reaction due to the a loads, assuming the flooring between floorbeams to act as a simple beam

82.216. *d.* **Unit Stresses—Steel Structures.**—Unless otherwise provid the several parts of a structure shall be so proportioned that the unit stres will not exceed the following, except as provided for structural-steel desi under combined stresses, secondary stresses and allowances for overlo Unless otherwise noted, all unit stresses are given in pounds per square ir

82.217. Structural Grade and Rivet Steel—Tensions.

Axial tension, structural members, net section..........16,

Rivets in tension, where permitted..50% of single shear val

Bolts, area at root of thread..........................10,

82.218. Structural Grade and Rivet Steel—Compression.

Axial compression, gross section..............15,000–50

but not to exceed 13,500

l = length of member, in inches

r = least radius of gyration, in inches.

82.219. Structural Grade and Rivet Steel—Bending on Extreme Fiber

Rolled shapes, built sections and girders, net section....16,

Pins..24,

32.220. Structural Grade and Rivet Steel—Shear.

Girder webs, gross section	10,000
Pins and shop-driven rivets	12,000
Power-driven field rivets and turned bolts	10,000
Hand-driven rivets and unfinished bolts	7,500

32.221. Structural Grade and Rivet Steel—Bearings.

Pins, steel parts in contact and shop-driven rivets	24,000
Power-driven field rivets and turned bolts	20,000
Hand-driven rivets and unfinished bolts	15,000
Expansion rollers, pounds per linear inch	600*d*

where d = diameter of roller in inches.

32.222. Structural Grade and Rivet Steel—Countersunk Rivets.

In metal ⅜″ thick and over, half the depth of countersink shall be omitted in calculating bearing area.

In metal less than ⅜″ thick, countersunk rivets shall not be assumed to carry stress.

32.223. Structural Grade and Rivet Steel—Diagonal Tension.

In webs of girders and rolled beams, at sections where maximum shear and bending occur simultaneously	16,000
Wrought iron—axial tension	12,000
Cast steel—bending on extreme fiber	12,000
Cast iron—bending on extreme fiber	3,000
Cast steel—shear	10,000
Cast iron—shear	3,000
Cast steel—bearing	14,000
Cast iron—bearing	10,000
Bronze sliding expansion bearings	3,000
Bearing on concrete masonry and limestone masonry and better	500

32.224. **Dimensions for Stress Calculation.**—For the calculation of esses, effective span lengths shall be assumed as follows:

Beams and girders, distance between centers of bearings. Trusses, disice between centers of end pins or of bearings. Floor beams, distance ween centers of trusses or girders. Stringers, distance between centers floorbeams.

32.225. For the calculation of stresses, effective depths shall be assumed as lows:

Riveted trusses, distance between centers of gravity of the chords.

Pin-connected trusses, distance between centers of chord pins.

Plate girders, distance between centers of gravity of the flanges but not to eed the distance back to back of flange angles.

32.226. **Reversal of Stress.**—Members subject to reversal of stress during passage of live load shall be proportioned as follows: Determine the isile and the compressive stresses and increase each by 50% of the smaller; n proportion the member so that it will be capable of resisting each inased stress. The connections shall be proportioned for the sum of the ginal stresses.

32.227. No pin-connected member shall be subjected to reversal of stress.

32.228. When the live-load and dead-load stresses are of opposite sign, y 70% of the dead-load stress shall be considered as effective in counterting the live-load stress.

32.229. **Combined Stresses.**—Members subject to both axial and bending esses shall be proportioned so that the combined fiber stresses will not eed the allowable axial stress. Members continuous over panel points ill be proportioned for live- and dead-load bending moments equivalent to ose computed for a simple beam having a span equal to one panel length.

32.230. **Stresses Due to Lateral and Longitudinal Forces and Temperure.**—In proportioning the various parts of the structure, provision shall be de for the following stress combinations:

Group A—Dead load; live load; impact; centrifugal force.

Group B—Lateral force; longitudinal force; temperature.

32.231. Members subject to the stresses of Group A in conbination with stresses of Group B, either direct or flexural or both, shall be designed any of the following combinations at unit stresses 25% greater than those cified, but the resulting sections shall be not less than would be required he stresses of Group A were considered alone.

1. The combined stresses of Group B in combination with dead load or
2. The combined stresses of Group A in combination with 50% of combined stresses of Group B.
3. The combined stresses of Group A in combination with temperat only.

82.232. Secondary Stresses.—Members and their details shall be prop tioned to reduce secondary stresses to a minimum. In simple trusses with subdivided panels the secondary stresses due to deformation in any mem whose width measured in the place of flexure is less than one-tenth of length need not be considered. When this ratio is exceeded, or where s divided panels are used, the secondary stresses shall be computed. members designed for secondary stresses in combination with other stres the specified allowable unit stresses may be increased 30%, but the secti shall be not less than required for primary stresses.

82.233. Allowance for Overload.—For the calculation of stress reversal counterstresses, the specified live loads, either uniform or concentrated, sl be increased 100 % and for this loading condition the specified unit stres shall be increased not more than 50 %. The resulting sections shall be less than would have been required had the allowance for overload not b considered.

82.234. Compression Flanges of Beams and Girders.—The gross area the compression flanges of beams and plate girders shall be not less than gross area of the tension flanges.

82.235. The laterally unsupported length of the compression flanges beams and girders shall not exceed forty times the flange width. When unsupported length of flange exceeds twelve times the flange width, the cc pressive stress in pounds per square inch shall not exceed:

$$19{,}000 - 250\frac{L}{b} \text{(maximum value, 16,000 lb.)}$$

where

L = length, in inches, of unsupported flange, between lateral connection knee braces.

b = flange width in inches.

82.236. Rolled beams shall be proportioned by the moments of inertia their sections. Proper allowances shall be made for any reduction in stren due to rivet holes in the tension flange or to any reduction in allowable st due to the length of unsupported compression flange.

82.237. Limiting Lengths of Members.—The ratio of unsupported len to the least radius of gyration shall not exceed 120 for main compression a stiffening members nor 140 for laterals and sway bracing. In proportion the top chords of low trusses the unsupported length shall be assumed as length between the rigid verticals.

82.238. For main riveted tension members the ratio of length to le radius of gyration shall not exceed 200.

82.239. Effective Bearing Area.—The effective bearing area of a pin, b or rivet shall be its nominal diameter multiplied by the thickness of the me on which it bears.

82.240. Effective Diameter of Rivets.—In proportioning rivets, the no nal diameter of the rivet shall be used.

82.241. Size of Rivets.—Rivets shall be of the size specified but genera shall be ¾ or ⅞" in diameter; ⅝" rivets shall not be used in members car ing calculated stress except in 2½" legs of angles and in flanges of 6 and beams and channels.

82.242. The diameter of rivets in angles carrying calculated stress sl not exceed one-fourth of the width of the leg in which they are driven. angles whose size is not so determined ⅝" rivets may be used in 2" legs, rivets in 2½" legs and ⅞" rivets in 3" legs.

82.243. In no case, except in handrails, shall structural shapes be u which do not admit the use of ⅝" diameter rivets.

82.244. Pitch of Rivets.—The minimum allowable distance betw centers of rivets shall be three times the diameter of the rivet, but prefera shall be not less than the following:

For ⅞" diameter rivets	3"
For ¾" diameter rivets	2½"
For ⅝" diameter rivets	2¼"

82.245. The maximum allowable pitch in the line of stress shall not exc 6" or sixteen times the thickness of the thinnest outside plate or an

nnected, except in angles having two gage lines with rivets staggered where e pitch in each line may be twice the above with a maximum of 10″.

82.246. In webs of members composed of two or more plates in contact, the vets shall be spaced not more than 10″ between centers in gage and pitch, ovided such rivets serve no other purpose than to hold the plates in close ntact. Tension members composed of two angles in contact shall be tch riveted, using a pitch not greater than 12″.

82.247. **Pitch in Ends of Compression Members.**—Panel points shall be nsidered as ends of compression members. In the ends of built com- ession members the pitch of rivets connecting the component parts of the ember shall not exceed four times the diameter of the rivet for a length ual to one and one-half times the maximum width of member. Beyond is point the rivet pitch shall be gradually increased for a length equal to e and one-half times the maximum width of the member until the maxi- im spacing is reached. In angles having two lines of staggered rivets, in e leg, the pitch on each line may be twice that specified above but not eater than that allowed for the body of the member.

82.248. **Edge Distance of Rivets.**—The minimum distance from the center any rivet to a sheared edge shall be:

For 7/8″ diameter rivets	1 1/2″
For 3/4″ diameter rivets	1 1/4″
For 5/8″ diameter rivets	1 1/8″

32.249. The minimum distance from rolled or planned edges, except nges of beams and channels, shall be:

For 7/8″ diameter rivets	1 1/4″
For 3/4″ diameter rivets	1 1/8″
For 5/8″ diameter rivets	1″

32.250. The maximum distance from any edge shall be eight times the ckness of the thinnest outside plate, but shall not exceed 5″.

32.251. **Long Rivets.**—Long rivets subject to calculated stress and having rip in excess of 4 1/2 diameters shall be increased at least 1% for each addi- nal 1/16″ of grip. If the grip exceeds six times the diameter of the rivet, cially designed rivets shall be used.

32.252. Rivets in direct tension shall, in general, not be used. However, ere so used their value shall be one-half that permitted for rivets in shear. untersunk rivets shall not be used in tension.

32.253. **Depth Ratios.**—Trusses preferably shall have a depth not less n 1/10 of the span, plate girders a depth not less than 1/12 of the span, and led beams a depth not less than 1/20 of the span. If less depths than these used, the sections shall be increased so that the maximum deflection will be greater than if these limiting ratios had not been exceeded.

32.254. **Parts Accessible.**—The accessibility of all parts of a structure for pection, cleaning, and painting shall be insured by the proper propor- ning of members and the design of their details.

32.255. **Open Sections and Pockets.**—Closed sections shall in general be oided. Pockets or depressions which will retain water shall be avoided far as possible and those which are unavoidable shall be provided with ective drain holes or shall be effectively filled with waterproof material.

32.256. Details shall be arranged so that the retention of dirt, leaves, or er foreign matter will be reduced to a minimum. Wherever angles are d, either singly or in pairs, they preferably shall be placed with the vertical s extending downward.

2.257. **Symmetrical Sections.**—Main members shall be proportioned so t their neutral axes shall be as nearly as practicable in the center of the ion.

2.258. In general, the gravity axes of main truss and other important mbers, meeting to form a joint, shall intersect in a common point so as to id eccentricity of stress. In cases of unavoidable eccentricity the mem- s affected thereby shall be proportioned and the connection details igned to resist the stresses produced.

2.259. **Effective Area of Angles in Tension.**—The effective area of single les in tension shall be assumed as the net area of the connected leg plus 5% of the area of the unconnected leg.

2.260. The effective area of a double-angle tension member shall be umed as 80% of the net area of the member unless the end details and

connections are such that the individual angles are held against bending both directions, in which case the full net area may be used. When tl angles connect to separate gusset plates, as in the case of a double-webb truss, the gusset plates shall be stiffened by diaphragms in the line of tl connected angles or by tie plates extending to the ends of the angles if th are to be considered as offering such resistance to bending that the full n area can be used. When the angles are connected back to back on the opp site sides of a single gusset plate, the support may be assumed to be sufficie to allow the use of the full net section.

82.261. Lug angles shall not be considered as effective in transmitti stress.

82.262. **Strength of Connections.**—Unless otherwise provided, all co nections shall be proportioned to develop not less than the full strength the members connected.

82.263. No connection, except for lacing bars and handrails, shall conta less than three rivets.

82.264. **Splices.**—Continuous compression members in riveted structur such as chords and trestle posts, shall have milled ends and full conta bearing at the splices.

82.265. All splices, whether in tension or compression, shall be prop tioned to develop the full strength of the members spliced and no allowan shall be made for milled ends of compression members.

82.266. Splices shall be located as close to panel points as possible and, general, shall be on that side of the panel point which is subjected to t smaller stress and outside of gusset plates.

82.267. The arrangement of the plates, angles or other splice elements sh be such as to make proper provision for the stresses in the component pa of the members spliced.

82.268. **Indirect Splices.**—In all splice plates not in direct contact with t parts they connect, the number of rivets on each side of the joint shall be excess of the number which would otherwise be required for a contact spl to the extent of two extra transverse lines for each intervening plate.

82.269. **Fillers.**—Where indirect splices involve rivets carrying stress a passing through fillers, the fillers shall be extended beyond the splic material and the extension secured by additional rivets sufficient in num to develop the section of the filler.

82.270. When the filler is less than ¼″ thick, the splicing materials sh also be extended.

82.271. **Gusset Plates.**—Gusset or connecting plates shall be used connecting all main members, except in pin-connected structures. In p portioning and detailing these plates, the rivets connecting each member sh be located, as nearly as practicable, symmetrically with the axis of member. However, the full development of the elements of the mem shall be given due consideration. The gusset plates shall be of ample thi ness to resist shear, direct stress and flexure acting on the weakest or criti section of maximum stress. Reentrant cuts shall be avoided as far possible.

82.272. **Minimum Thickness of Metal.**—The minimum thickness structural steel shall be 5⁄16″ except for fillers and railings. However, gus plates shall not be less than ⅜″ in thickness.

82.273. Metal subjected to marked corrosive influence shall be increa in thickness.

82.274. Cast steel shall not be less than 1″ and cast iron not less than 1½ thick, except for filler blocks.

82.275. **Compression Members.**—In built compression members metal shall be concentrated as much as possible in the webs and flanges, that the center of gravity of the section may be near the center line of member as practicable.

82.276. **Plates in Compression.**—Cover plates of built compression me bers and cover plates on the compression flanges of plate girders shall ha a minimum thickness of one-fortieth, and the web plates of compress members a minimum thickness of one-thirtieth, of the transverse dista between the lines of rivets connecting them to the flanges. However, fail to meet this requirement, the width of plate between the connecting lines rivets in excess of forty times the thickness for cover plates and thirty ti the thickness for web plates, shall not be considered as effective in resist stress.

82.277. **Outstanding Flanges.**—Outstanding compression flanges girders and main compression members shall have a minimum thickness

ne-twelfth of the width of outstanding flange. For lateral bracing and other secondary members this minimum thickness may be one-fourteenth of the width of the outstanding flange.

82.278. **Tie Plates.**—The open sides of compression members shall be provided with lacing bars and shall have tie plates as near each end as practicable and at intermediate points where the lacing is interrupted. Compression members composed of two angles and cover plates shall have, on their open sides, ties composed of short lengths of channel section with the flanges riveted to the vertical legs of the angles.

82.279. Tension members composed of shapes shall have their separate segments connected by tie plates or by tie plates and lacing bars.

82.280. The thickness of the tie plates shall be not less than one-fiftieth of the distance between the connecting lines of rivets. The tie plates shall be connected by not less than three rivets on each side, and in members having lacing bars the last rivet in the tie plate shall preferably also pass through the end of the adjacent bar.

82.281. For main compression members, the end tie plates shall have a length not less than one and one-half times the perpendicular distance between the lines of rivets connecting them to the member and with a rivet spacing of the preferred minimum and the intermediate tie plates a length not less than that distance. For main tension members the end tie plates shall have the length above specified for end tie plates on main compression members and the length of the intermediate tie plates shall not be less than three-fourths the length specified for intermediate tie plates on compression members. In tension members whose elements are connected by tie plates only, the distance center to center of plates shall not exceed 3′.

82.282. For lateral struts and other secondary members, the length of end and intermediate tie plates shall be not less than three-fourths the perpendicular distance between the lines of rivets connecting them to the member.

82.283. **Lacing Bars.**—The lacing of compression members shall be proportioned to resist a transverse shear not less than that calculated by the formula:

$$S = 300A.$$

where S = transverse shear, in pounds.
A = gross area of member, in square inches.

82.284. This shear shall be considered as divided equally among all stiffening parts in parallel planes, whether made up of continuous plates or lattice. The stress in the individual lacing bar shall be taken as the component of the shear, in the direction of the bar, in case single lacing is used and half that amount if double lacing is used. The size of the bar shall be determined by the column formula in which L shall be taken as the distance between the connections to the main sections.

82.285. The minimum width of lacing bars shall be:

For ⅞″ diameter rivets	2½″
For ¾″ diameter rivets	2¼″
For ⅝″ diameter rivets	2″

82.286. Lacing bars having two rivets in each end shall be used for flanges 5″ or more in width.

82.287. The minimum thickness of bars shall be one-fortieth of the distance between end rivets in the case of single lacing and one-sixtieth of this distance for double lacing.

82.288. Double lacing, riveted at the intersections, shall be used when the perpendicular distance between rivet lines exceeds 15″.

82.289. The inclination of single lacing shall generally be about 60° and for double lacing it shall be about 45° to the axis of the member. Furthermore, the maximum spacing of lacing bars shall be such that the ratio of length to radius of gyration $\left(\frac{L}{r}\right)$ for the portion of single flange between consecutive connections will be smaller than this ratio for the member as a whole.

82.290. Shapes of equivalent strength may be used instead of flats.

82.291. **Net Section at Pins.**—Pin-connected riveted tension members shall have a net section, both through the pin hole and back of the pin hole, at least 25% in excess of the net section of the body of the member.

82.292. **Net Section of Riveted Tension Members.**—In calculating the required area of riveted tension members, net sections shall be used in all

cases, and in deducting rivet holes they shall be taken as ⅛″ larger than th nominal diameter of the rivet.

82.293. The net section shall be the least area which can be obtained b deducting from the gross sectional area, the area of holes cut by any straigh or zigzag section across the member, counting the full area of the first ho and a fractional part of each succeeding hole, the fractional part bein determined by the formula:

$$x = 1 - \frac{S^2}{4gh}$$

where x = fraction of rivet hole to be deducted.
S = stagger or longitudinal spacing of rivets with respect to rive on last gage line.
g = distance between gage lines, or transverse spacing.
h = diameter of rivet holes, or nominal diameter of rivet plus ⅛″

82.294. Location of Pins.—Pins shall be located, with respect to the neutr axis of the members, so as to reduce to a minimum secondary stresses due bending.

82.295. Pin Plates.—Pin plates shall be of sufficient thickness to provid the required bearing area upon the pin; they shall be as wide as the dime sions of the member will allow; and their length, measured from pin cent to end, shall be at least equal to the width. Pin plates shall contain sufficie rivets to distribute their due proportion of the pin pressure to the full cros section of the members; only the rivets located within two lines drawn fro the pin center toward the body of the member and inclined at 45° to the ax of the member shall be considered effective for this purpose. In the case members composed of web plates and flange angles (with or without a cov plate), there shall be at least one outside pin plate covering the vertical le of the flange angles.

82.296. At the ends of compression members at least one pair of pin plat shall extend not less than 6″ beyond the near edge of the tie plate.

82.297. All pin-connected compression members shall be provided wi hinge plates having a minimum thickness of ⅜″.

82.298. Forked Ends.—Forked ends on compression members will permitted only when unavoidable. When used, a sufficient number of p plates shall be provided to give each jaw the full strength of the compressi member. At least one pair of these plates shall extend to the far edge the tie plates, and the others not less than 6″ beyond the near edge of the plates.

82.299. Pins and Pin Nuts.—Pins shall be proportioned for the maximu shears and bending moments by the stresses in the members connecte If there are eyebars among the parts connected, the diameter of the p shall be not less than two-thirds of the width of the widest bar attache Pins shall be of sufficient length to secure a full bearing of all parts connect upon the turned body of the pin. They shall be secured in position by hex gonal chambered nuts or by hexagonal solid nuts with washers. Where t pins are bored, through rods with cap washers may be used. In gener malleable castings conforming to the requirements of Material Details, Ite 100.28, shall be used for pin nuts. Pin nuts shall be secured by cotters the screw ends.

82.300. Bolts.—Unless specifically authorized, bolted connections w not be permitted. Bolts, when used, shall be unfinished or turned as specifi and shall meet the requirements of Item 59.31.

82.301. Bolts in tension shall have double nuts.

82.302. Upset Ends.—Bars and rods with screw ends shall be upset provide a cross-sectional area at the root of the thread which shall exce the net section of the body of the member by at least 15%.

82.303. Sleeve Nuts.—Sleeve nuts shall not be used.

82.304. Expansion.—Provision for expansion and contraction, to t extent of ⅛″ for each 10′ of span, shall be made for all bridges. Expansi ends shall be firmly secured against lifting or lateral movement.

82.305. Expansion Bearings.—Spans of less than 70′ may be arranged slide upon metal plates with smooth surfaces. Spans of 70′ and over sh be provided with rollers or rockers or with the special sliding bearin described below. Neither rollers nor rockers shall be used for expansi bearings at the top of trestle posts.

82.306. Fixed Bearings.—Fixed bearings shall be firmly anchored.

82.307. Hinged or Pin Bearings.—Spans of 70′ and over shall have hing or pin bearings at both ends. The pedestals or shoes shall be so design

hat all loads will act through the end pins which will be located directly over the geometrical center of the bearings.

82.308. Rollers.—Expansion rollers shall be not less than 4″ in diameter for span lengths of 100′ or less and this minimum shall be increased not less than 1″ for each additional 100′ of span, and proportionally for intermediate lengths. They shall be connected together by substantial side bars and shall be effectually guided so as to prevent lateral movement, skewing, or creeping. The rollers and bearing plates shall be protected from dirt and water as far as possible, and the construction shall be such that water will not be retained and that the roller nests may be inspected and cleaned with the minimum difficulty.

82.309. Rockers.—Pin-bearing expansion rockers shall be of cast steel or cast iron.

82.310. Special Sliding Expansion Bearings.—Sliding plates for the expansion bearings of spans of 70′ and over shall be of Class A bronze, as prescribed under item Structural Steel. These plates shall be chamfered at the ends and shall be held securely in position, usually be being inset into the metal of the pedestals and sole plates. Provision shall be made against any accumulation of dirt which will obstruct their movement.

82.311. Pedestals and Shoes.—Pedestals and shoes shall be designed to secure rigidity and stability and to distribute the reaction uniformly over the entire bearing area. Preferably, they shall be made of cast steel or structural steel. The bottom bearing widths shall not exceed the top bearing widths by more than twice the depth of pedestal and, when involving pin bearings, this depth shall be measured from the center of pin.

82.312. Where built pedestals and shoes are used, the web plates and the angles connecting them to the base plates shall be not less than ½″ thick. If the size of the pedestal permits, the webs shall be rigidly connected transversely.

82.313. Inclined Bearings.—For spans on an inclined grade and without pin or hinged bearings, the sole plates shall be beveled so that the substructure bridge seats will be level.

82.314. Anchor Bolts.—Trusses, girders, and I-beam spans shall be securely anchored to their substructures. Anchor bolts shall be roughened by being screw threaded or swedged to secure a satisfactory grip upon the material used to embed them in the holes.

82.315. The following are the minimum requirements for each bearing:

For I-beams spans, the outer beam shall be anchored at each end with two bolts
1″ in diameter, set 10″ in the masonry.
For girder and truss spans, 50′ in length or less, 2 bolts
1″ in diameter, set 10″ in masonry.
51 to 100′ in length, 2 bolts, 1¼″ in diameter, set 1′ 0″ in masonry.
101 to 150′ in length, 2 bolts, 1½″ in diameter, set 15″ in masonry.
151 to 250′ in length, 4 bolts, 1½″ in diameter, set 1′ 6″ in masonry.

82.316. Anchor bolts subject to tension, as in the column bases of trestle bents and towers, shall be designed to engage a mass of masonry which will secure a resistance equal to one and one-half times the calculated uplift.

Floor System

82.317. Floorbeams.—Floorbeams preferably shall be at right angles to the trusses or main girders and shall be rigidly connected thereto. In general, floorbeam connections shall be located above the bottom chord, and in riveted work the bottom-chord lateral system shall engage both the bottom chord and the floorbeam. Floorbeam connections to pin-connected trusses preferably shall be above the bottom-chord pins, but, if located below, the vertical posts shall be extended below the pins to secure rigid connections to the floorbeams.

82.318. End Floorbeams.—Except in skew bridges, end floorbeams shall be provided in all truss and girder spans. End floorbeams preferably shall be designed to permit the use of jacks for the future lifting of the superstructure, under which condition the specified unit stresses shall not be exceeded by more than 50%.

82.319. End floorbeams shall be arranged to permit future painting of the sides of the beams adjacent to the abutment backwalls.

82.320. Stringers.—Steel stringers preferably shall be riveted between th floorbeams, with end connections to the floorbeam webs.

82.321. End Struts.—When end floorbeams are not used, the end-pan stringers shall be secured in correct locations by end struts securely cor nected to the stringers and to the main trusses or girders. The end-pan lateral bracing shall be rigidly attached to the main trusses or girders an shall also be attached to the end struts. Adequate provision shall be mac for the expansion movement of stringers.

82.322. End Connections for Floorbeams and Stringers.—The end-cor nection angles of floorbeams and stringers shall be not less than 3/8″ i thickness. When milled ends are required, the thickness of connectio angles shall be 1/16″ greater than for connection angles not required to b milled. Except in cases of special end floorbeam details, end connectior for floorbeams and stringers shall be made with two angles at each enc Bracket or shelf angles which may be used to furnish support during erectio shall not be considered in determining the number of rivets required t transmit end shears.

82.323. End-connection angles shall develop the full depth of the webs b having a length as great as the flanges will permit.

82.324. In the preparation of end-connection details, special care shall b exercised to provide ample clearance for the driving of field connection rivet

82.325. The use of any type of floorbeam hanger which does not prever all rotation or longitudinal motion of the floorbeam will not be permitted.

82.326. Expansion Joints.—To provide for expansion and constructic movement, suitable floor expansion joints shall be provided at the expansic ends of all spans and at other points where they may be required.

82.327. Apron plates, when used, shall be designed properly to bridge tl joint and to prevent, as far as possible, the deposit of roadway debris upc the bridge seat.

Bracing

82.328. Design of Bracing.—Lateral, longitudinal, and transverse bracir shall be composed of angles or other shapes offering resistance to deformatic when subjected to compressive stress, and shall have riveted connections.

82.329. In general, bracing shall consist of a double system of diagon tension members with transverse compression members. The diagonals each system shall be proportioned to carry the total lateral stress in tensio the transverse struts (or floorbeams) acting as compression members of bo systems.

82.330. All intersections of lateral and sway bracing shall be riveted to ac rigidity and prevent deformations.

82.331. Lateral Bracing.—Bottom lateral bracing shall be provided in a bridges except I-beam spans, from which it may be omitted. Bottom latera preferably shall be supported by rigid hangers at the intersections.

82.332. Top lateral bracing shall be provided in deck spans and in throug spans having sufficient headroom.

82.333. Lateral bracing for compression chords shall preferably consist either two or four angle latticed sections; and so designed as to effective engage both flanges of the chords.

82.334. Lateral bracing shall have concentric connections to chords at en joints, and preferably throughout. The connections between the later bracing and the chords shall be designed to avoid, as far as possible, an bending stress in the truss members.

82.335. Portal and Sway Bracing.—Through truss spans shall have port bracing, preferably of the two-plane or box type, rigidly connected to the en post and top chord flanges, and constructed as deep as the minimum clearanc will allow. When a single-plane portal is used, it preferably shall be locate in the central transverse plane of the end posts, with diaphragms betwee the webs of the posts to provide for a proper distribution of the portal stresse The portal bracing shall be designed to take the full end reaction of the to chord lateral system and the end posts shall be designed to transfer th reaction to the truss bearings.

82.336. Deck truss spans shall have adequate sway bracing at the enc and at all intermediate panel points. This bracing shall occupy the fu depth of the trusses below the floor system. The bracing shall be propo tioned to transfer the end reaction of the top lateral system to th substructure.

82.337. Through truss spans shall have sway bracing at each intermediat panel point if the height of the trusses is such as to permit a depth of 5′ c

ıore for the bracing. When the height of the trusses will not permit of such epth, the top lateral struts shall be provided with knee braces. Top lateral truts shall be at least as deep as the top chord. Sway bracing shall be of mple strength to transfer one-half of the wind pressure to the leeward russ.

82.338. **Cross-frames.**—Deck plate-girder spans shall be provided with ross-frames at each end proportioned to resist all lateral forces and shall ave intermediate cross-frames at intervals not exceeding 15′. These ames shall be connected to the outstanding lags of the stiffener angles and the girder flanges.

82.339. **Low Truss Spans.**—The vertical truss members and the floorbeam onnections of low truss spans shall be proportioned to resist a lateral force, pplied at the top-chord panel points of the truss determined by the following quation:

$$R = 150\,(A + P)$$

here R = lateral force in pounds.
A = area of cross-section of chord in square inches.
P = panel length in feet.

82.340. This rigidity may be secured in part by extending one or both of e floorbeam connection angles upward along the inside of the post. Pref-ably outrigger brackets attached to the vertical posts on the outside of the usses shall not be used.

82.341. **Through Girder Spans.**—Through plate-girder spans shall be iffened against lateral deformations by means of gusset plates, or knee races with solid webs, attached to the stiffener angles and floorbeams. If e unsupported length of the inclined edge of the gusset plate exceeds xty times its thickness, the gusset plate shall have stiffener angles riveted ong its edge.

82.342. These braces generally shall extend to the clearance line and pref-ably shall be spaced not farther apart than 15′.

82.343. **Railings.**—Substantial railings shall be provided along each side the bridge for the protection of traffic. In general, the railings shall be vo classes, *viz.:*

1. Railings suitable for use on country bridges which are not subject to eneral pedestrian traffic.
2. Railings for the protection of pedestrians on bridge in cities or villages.

82.344. The top rail of all railings shall be located approximately 3′ 6″ oove the bridge floor and shall be capable of resisting a horizontal force of o lb. per linear foot.

82.345. Railings of the first class may consist of not less than two lines of orizontal rails of approved section.

82.346. Railings of the second class shall consist of an upper and lower orizontal rail connected by a suitable web. The clear distance between e floor and the lower rail shall not exceed 6″.

82.347. Preferably the unsupported length of any rail section shall not ceed 8′ and all connections to posts, truss members, etc. shall contain ot less than two rivets each. Ample provision shall be made for move-ent due to temperature.

Plate Girders

82.348. **Proportioning.**—Plate girders shall be proportioned either by suming the flanges to be concentrated at their centers of gravity or by e moment of inertia of the net section. In the former case one-eighth of e gross area of the web is available as net flange area, but the effective pth shall not be assumed to be greater than the distance back to back of nge angles. For girders having unusual cross-sections, the moment-of-ertia method shall be used.

82.349. **Flange Sections.**—The gross section of the compression flange all be not less than the gross section of the tension flange. The com-ession flange preferably shall be stayed against lateral deflection at inter-ls not exceeding twelve times its width.

82.350. The flange angles shall form as large a portion of the gross area the flange as practicable.

82.351. When flange cover plates are used, at least one plate on the top nge shall extend the full length of the girder. Any additional flange ver plates shall be of such length as to allow two rows of rivets to be aced at each end of the plate beyond its theoretical end, and there shall be sufficient number of rivets at the ends of each plate to develop its full ress value before the theoretical end of the next outside plate is reached.

82.352. Flange cover plates shall be equal in thickness, or shall diminis in thickness from the flange angles outward. No plate shall have a thicl ness greater than that of the flange angles.

82.353. Web Plates.—Web plates shall be proportioned for both tl vertical and horizontal shearing stresses. Splices in web plates shall l avoided as far as possible, but, when used, they shall be designed to develc the full value of the web plate for both bending and shearing stresses.

82.354. Flange Rivets.—The number of rivets connecting the flan angles to the web plates shall be sufficient to develop the increment flange stress transmitted to the flange angles, combined with any load th is applied directly to the flange. For electric railways, one-wheel loa when applied directly to the flange, shall be assumed to be distribute uniformly over a length of 3′.

82.355. Flange Splices.—Splices in flange members shall not be us except by special permission of the engineer. Two members shall not l spliced at the same cross-section, and if practicable, splices shall be locat at points where there is an excess of section. The net section of the spli shall exceed by 10% the net section of the member spliced. Flange ang splices shall consist of two angles, one on each side. Splice angles sh be fitted to secure close contact with the material spliced.

82.356. Web Splices.—Web plates shall be symmetrically spliced l plates on each side. The splice shall be equal in strength to the web both shear and moment. There shall be at least two rows of rivets on ea side of the joint.

82.357. End Stiffeners.—Plate girders shall have stiffener angles over e bearings, the outstanding legs of which shall be as wide as the flange ang will allow and shall fit tightly against them. These end stiffeners shall proportioned for bearing on the outstanding legs of the flange angles, allowance being made for the legs fitted to the fillets of the flange angl End stiffeners shall be arranged to transmit the total end reaction and distribute it over the bearings. They shall not be crimped and the cc nection to the web shall contain a sufficient number of rivets to transmit t entire reaction.

82.358. Intermediate Stiffeners.—Intermediate-stiffener angles shall riveted in pairs to the web of the girder. The outstanding leg of ea angle shall have a width of not more than sixteen times its thickness a not less than 2″ plus one-thirtieth of the depth of the girder.

82.359. Intermediate stiffeners shall be spaced at intervals not exceedi

a. Six feet.
b. The depth of the web.
c. The distance given by the formula.

$$d - \frac{t}{40}(12{,}000\text{-}S)$$

where d = distance between rivet lines of stiffeners in inches.
t = thickness of web in inches.
s = web shear in pounds per square inch at the point considered.

82.360. When the depth of the web between the flange angles or s plates is less than sixty times the web thickness, intermediate stiffen may be omitted.

82.361. Intermediate-stiffener angles shall be placed at points of c centrated loading and shall be designed to transmit the reactions to girder web. Such stiffeners shall not be crimped. Other intermedi stiffeners may be crimped.

82.362. Ends of Through Girders.—The upper corners of through pl girders, where exposed, shall be neatly rounded to a radius consistent w the size of the flange angles and the vertical height of the girder above roadway. The first flange plate or a plate of the same width will be b around the curve and continued to the bottom of the girder. In a bri consisting of two or more spans, only the corners on the extreme ends n to be rounded, unless the spans have girders of varying heights, in wh case the higher girders shall have their top flanges neatly curved down at ends to meet the top corners of the girders in the adjacent spans.

82.363. End Bearings.—End bearings of girders on masonry shall raised above the bridge seat by metal pedestals or plates a height of least 2″.

82.364. Sole and Masonry Plates.—Sole and masonry plates shall e be not less than ¾″ thick.

82.365. Camber.—In general, camber will not be required in plate girders xcept for long spans or special conditions. When used, it shall be sufficient ı amount to meet the requirements of the engineer.

TRUSSES

82.366. Main Features.—Preference will be given to trusses with single ıtersecting web members or other forms of trusses possessing the least mbiguity in computed stresses and the greatest elements of serviceability. .djustable members in any part of the structure preferably shall be avoided. Iembers shall be symmetrical about the central plates of trusses and all arts shall be so designed that they can be inspected, cleaned and painted.

82.367. Through riveted and pin-connected spans will generally have ıclined end posts. Low truss spans shall be of the riveted type. In low uss spans, laterally unsupported hip joints or "flying hips" shall be avoided.

82.368. Top Chords and End Posts.—Top chords and end posts of low and ırough truss spans shall be made usually of two side segments with one ›ver plate and with tie plates and lacing on the open side. In chords of ght section, tie plates and lacing may be used in place of a cover plate.

82.369. Top chords of deck trusses subjected to direct loading shall be esigned for the cross-bending occasioned by the dead, live, and impact ads of the floor system, in addition to the direct chord stresses, and all p-chord splices shall be proportioned for those stresses and any shearing resses they may receive. Where the shape of the truss permits, compression ıords shall be built continuous, with splices located as near the panel points possible and preferably on the side subjected to the smaller stress.

82.370. The top-chord sections of low truss spans shall be so proportioned at the radius of gyration about the vertical axis of the member shall be at ast one and one-half times the radius of gyration about the horizontal axis.

82.371. Bottom Chords.—The bottom chords of riveted trusses generally all be spliced outside of gusset plates near panel points and on the side rthest away from the center of the span.

82.372. Bottom chords composed of angles preferably shall be detailed with e vertical legs of the angles extending downward.

82.373. Working Lines and Gravity Axes.—For compression members rmed of side segments and a cover plate, the working line shall coincide as arly as practicable with the gravity axis of the section. For symmetrical ctions the working line shall coincide with the gravity axis. For two angle ›ttom chord or diagonal members, the working line may be taken as the ge line nearest the back of the angle.

82.374. Camber.—Trusses shall in general be given a camber by increasing e length of the top chords an amount in each panel length equal to $\frac{3}{16}''$ r each 10′ of their horizontal projection.

82.375. Rigid Members in Pin-connected Trusses.—Pin-connected usses shall have stiff riveted members in the bottom chords of the first o main panels at each end of the span and all web members performing the nction of suspenders shall be of stiff riveted construction.

82.376. Counters and Adjustable Members.—Rigid counters are preferred. ljustable counters, when used, shall have open turnbuckles and in the sign of these members an allowance of 10,000 lb. shall be made for initial ess. Only one set of diagonals in any panel shall be adjustable. Sleeve ts and loop bars shall not be used.

82.377. Eyebars.—Eyebar heads shall have a cross-sectional area through e center of the pin hole exceeding that of the body of the bar by at least 40%. ıe net section adjacent to the head shall be not less than that of the main dy of the bar. The thickness of the bar shall be not less than one-eighth the width and greater than 2″. The forms of the head shall be submitted the engineer for approval before the bars are made. The diameter of the ı shall be not less than two-thirds of the width of the widest bar connected.

82.378. Packing Eyebars.—The eyebars of a set shall be packed symmet- ally about the central plane of the truss and as nearly parallel as practi- ble, but in no case shall the inclination of any bar to the plane of the truss ceed $\frac{1}{16}''$ per foot. Bars shall be packed as closely as practicable and ld against lateral movement, but they shall be arranged so that adjacent rs in the same panel will be separated by at least $\frac{3}{4}''$.

82.379. All intersecting diagonal bars not far enough apart to clear each ıer at all times shall be well clamped together at intersections.

82.380. Steel filling rings shall be provided, when required, to prevent eral movements of eyebars or other members connected upon pins.

82.381. **Diaphragms.**—Diaphragms shall be provided in the trusses at t end connections of all floorbeams. In general, such diaphragms shall exte down to the bottom flange of the floorbeam and for at least two rivet spa above the top flange.

82.382. The gusset plates engaging the pedestal pin at the end of a tr shall be rigidly connected by a diaphragm which shall, in general, take dir bearing on the pin. Similarly, the pedestal webs shall, where practicable, connected by diaphragms which shall in general take bearing on the bea

82.383. A diaphragm shall be provided between gusset plates engag main members whenever the end tie plate is located at a distance of 4' more from the point of intersection of the members. In general, the wet this diaphragm shall be located in the plane of the latticed flange.

82.384. **Sole and Masonry Plates.**—Sole and masonry plates support trusses and columns shall each have a thickness of not less than ¾". T bottom chords of trusses shall be raised above the bridge seat at least by the use of metal plates or pedestals.

Viaducts

82.385. **Type.**—Viaducts shall consist usually of alternate tower spans a free spans of plate girders or riveted trusses supported on trestle tow However, in viaducts having a column height less than 35', trestle bents n alternate with the towers.

82.386. In viaducts requiring freedom of waterway and in structu having a less total column height than 20', the number of intermediate tre bents may be increased over that specified above but, in general, shall exceed four in number. Ample rigidity shall be secured in the attachmen the superimposed spans to the column caps of the bents.

82.387. **Bents and Towers.**—Each trestle bent shall be composed p erably of two main supporting columns. Towers shall be composed of bents rigidly braced and strutted both longitudinally and transversely.

82.388. **Single Bents.**—Where viaduct spans are supported on sin bents, such bents, if less than 20' in height, shall be pin connected to t base sections or shall be designed to resist bending.

82.389. **Batter.**—Columns preferably shall have a transverse batter of less than 1 horizontal to 12 vertical.

82.390. **Depth of Girders.**—The depth of plate girders in viaducts p erably shall be uniform.

82.391. **Girder Connections.**—Girders of tower spans shall be fastene each end to the tops of the columns or to the cross-girders. Girders betw towers shall have one end riveted, and shall be provided with an effec expansion joint at the other end. No bracing or sway frame shall be c mon to abutting spans.

82.392. **Bracing.**—Towers shall be thoroughly braced, both transver and longitudinally, with a double system of stiff tension diagonals v riveted connections. Longitudinal and transverse struts shall be place caps and bases and at all intermediate panel points. All bracing c nections are to be made by gusset plates.

82.393. Column splices generally shall be located close to and above panel points of the bracing.

82.394. Horizontal diagonal bracing shall be provided at the tops bases of towers and at least at all intermediate panel points of the lat bracing where the tower columns are spliced.

82.395. Provision shall be made in column bearings for expansion of to bracing. The struts at the base of towers shall be strong enough to slide movable shoes with the structure unloaded. The coefficient of friction s be taken at 0.3.

82.396. **Sole and Masonry Plates.**—Sole and masonry plates shall e be not less than ¾" thick.

82.397. **Anchorage.**—Viaduct bents preferably shall have a suffic spread at the base to prevent tension in any windward leg. When th impracticable, the column anchorages shall be designed safely to resist less than one and one-half times the calculated uplift.

82.398. **Method of Measurement.**—The quantities of the various items which constitute the structure constructed and completed in accorda with this specification and accepted, shall be measured for payment accor to the plans and specifications for the several items, and in terms of corresponding units prescribed for the several pay items.

82.399. **Basis of Payment.**—These measured quantities shall be paid fo the contract unit prices bid for the several pay items, which payment

rices shall be full compensation for furnishing, fabricating, transporting nd erecting all materials, for all shop work, painting and field work, for ll labor, equipment, tools and incidentals necessary to complete the structures ready for use.

STANDARD SPECIFICATIONS
FOR
HIGHWAY BRIDGES AND INCIDENTAL STRUCTURES
AMERICAN ASSOCIATION OF STATE HIGHWAY OFFICIALS

June 1, 1925

Introduction

These standard bridge specifications have been prepared for the purpose f encouraging and promoting a more uniform practice in the design and onstruction of highway bridges.

The intent has been to put forth specifications susceptible of the widest ossible application and in their preparation the existing range of conditions and practices has been carefully studied, and coordinated in all essential lements to the greatest extent practicable.

The specifications have been written primarily to meet the needs of the tate bridge engineers for a complete working specification. The requirements, therefore, have been made consistently definite, but it is recognized hat, in individual cases, local or sectional limitations may make some nodifications necessary.

In scope, the specifications are limited to the field of ordinary highway ridges and do not provide for unusual span lengths and types of construction, for which provision must be made by special or supplemental pecifications.

The engineers who, as members of the subcommittee on Bridges and tructures of the American Association of State Highway Officials, have been esponsible for their production are as follows:

E. F. Kelley, U. S. Bureau of Public Roads, Washington, D. C., Chairman.
E. E. Brandow, State Department of Highways, Pennsylvania, Secretary.
J. H. Ames, State Highway Commission, Iowa.
Charles E. Andrew, State Highway Department, Washington.
W. C. Buetow, Resigned, formerly with State Highway Commission, Visconsin.
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W. C. Burnham, State Highway Commission, Oklahoma.
William L. Craven, State Highway Commission, North Carolina.
L. N. Edwards, State Highway Commission, Maine.
J. T. Ellison, State Highway Department, Minnesota.
William R. Glidden, State Highway Commission, Virginia.
C. L. Hussey, State Board of Public Roads, Rhode Island.
C. B. McCullough, State Highway Commission, Oregon.
Charles A. Mead, State Board of Public Utility Commissioners, New ersey.
H. E. Sargent, State Highway Board, Montpelier, Vt.
S. B. Slack, State Highway Department, Georgia.
L. G. Smith, State Highway Department, Alabama.
William J. Titus, State Highway Commission, Indiana.
M. W. Torkelson, State Highway Commission, Wisconsin.
H. E. Warrington, Resigned, formerly with State Highway Commission, alifornia.
G. G. Wickline, State Highway Department, Texas.
R. B. Wright, U. S. Bureau of Public Roads, Portland, Ore.

SECTION 18

PAVING BLOCKS

Asphalt Blocks

1. General.—Asphalt blocks shall be composed of asphaltic cement, ineral aggregate and inorganic dust, as herein specified, thoroughly mixed hile hot in such proportions, depending on their character, that the finished ocks shall conform to the specified requirements.

The ingredients of the blocks shall be tested in accordance with the ethods provided in the tentative Standard Methods of Sampling and esting of the American Association of State Highway Officials.

Each bidder shall submit with his bid a specimen block of the size a quality described in these specifications, labeled with the name of bidder, the name of the manufacturer, and the place of manufacture. B not accompanied by specimen blocks will not be accepted.

2. **Asphaltic Cement.**—The asphaltic cement shall conform to the foll ing requirements:

1. It shall be homogeneous and free from water.
2. Specific gravity 25°/25°C. (77°/77°F.), not less than 1.00.
3. Flash point: Not less than 190°C. (374°F.).
4. The penetration at 25°C. (77°F.), 100 g., 5 sec. shall be varied to climatic and traffic conditions in accordance with the following table:

Traffic	Temperature		
	Low	Moderate	High
Light	15–25	15–25	10–15
Moderate	15–25	15–20	10–15
Heavy	15–20	10–20	5–15

5. Loss on heating: At 163°C. (325°F.), 50 g., 5 hr., not more than 2%
6. Penetration of residue after heating: At 25°C. (77°F.), 100 g., 5 s as compared to penetration before heating, not less than 50%.
7. Ductility: At 25°C. (77°F.), not less than 5.
8. Proportion of bitumen soluble in carbon tetrachloride: not less t 99%.

3. **Mineral Aggregate.**—The mineral aggregate shall be clean, ha unweathered trap rock, dolomite, limestone, copper conglomerate, or ot suitable material which shall show a percentage of wear of not more than Its grading shall be such as to produce, with the inorganic dust, the m composition hereinafter specified.

4. **Inorganic Dust.**—The inorganic dust, or filler, shall be produced f sound limestone or other approved material and shall be powdered to suc fineness that 95% shall pass a 30-mesh sieve and not less than 50% s pass a 200-mesh sieve. Sufficient inorganic dust shall be used to give mesh composition hereinafter specified.

5. **Manufacture of Blocks.**—Before being mixed, the asphaltic cement crushed mineral aggregate shall be heated separately. In no case s either be heated to a higher temperature than 350°F., but the tempera of each shall be so regulated that the temperature of the block mixtur delivered to the press molds shall be not less than 225°F.

The mineral aggregate, inorganic dust, and asphaltic cement in the pr proportions shall be thoroughly mixed to produce a homogeneous mas which all particles are thoroughly coated with asphaltic cement.

The blocks shall receive a compression in the molds of not less than 4 lb. per square inch, applied on the 5 by 12″ surface. After pressing t shall be cooled by passing through water or by other suitable means.

6. **Characteristics of Finished Blocks.** *Size and Shape.*—The blocks s be 5″ in width by 12″ in lengths unless the depth required is less than 2″ which case they shall be 4″ in width by 8″ in length. The depth shall b shown on the plans. A variation either way from these dimensions of in length or ⅛″ in width or depth will be sufficient cause for rejection of block.

Composition.—The composition of the blocks, as delivered on the w shall conform to the following requirements:

Retained by ¼″ screen (circular openings)	not more than 1
Passing ¼″ screen and retained by 20-mesh sieve	30 to 60%
Passing 20-mesh sieve and retained by 100-mesh sieve	15 to 35%
Passing 100-mesh sieve (including all fines)	20 to 40%
Passing 200-mesh sieve	not less than 15
Bitumen content	6½ to 9%

Specific Gravity.—The blocks shall have a specific gravity of not less t 2.35 at 77°F.

Absorption Test.—The blocks to be tested shall be cleaned of loose partic carefully weighed, placed in a pressure vessel and subjected to a vacu

f 23″ for 1 hr. at room temperature. While still maintaining the vacuum, ater shall then be admitted to the vessel until the blocks are completely nmersed, after which the vacuum shall be relieved and water pressure arried up to 100 lb. per square inch and there maintained for 1 hr. The locks shall then be removed from the vessel and, after mopping off all urface water, shall be carefully weighed. The average of a set of four locks tested in this manner shall show absorption not exceeding one-half f 1 per cent by weight.

Asphalt-block Wearing Surface

15. **General Requirement.**—Asphalt-block wearing surfaces for concrete oors shall be placed only after the concrete floor has been thoroughly cured.

16. **Materials.**—All materials used in the construction of asphalt-block earing surfaces shall conform to the requirements of Division II. Sand r the mortar bed shall conform to the requirements for Grade B fine ggregate.

17. **Preparation of Subfloor.**—After the concrete floor slab has been proply cured, and immediately before the mortar bed is placed, the surface the slab shall be thoroughly hand broomed with stiff-wire or fiber brooms remove all dust or foreign materials adhering to the surface.

18. **Mortar Bed.**—The mortar bed shall consist of sand and Portland ment, in the proportion of 1 part cement to 4 parts sand, mixed with fficient water to moisten the ingredients thoroughly and to make a mortar such consistency that it can easily be spread upon the foundation and ruck with a template to a smooth and even surface. It must not, however, so soft as to allow the blocks to sink into the mortar when they are placed ereon.

The mortar bed shall be spread on the foundation slab and evenly disibuted thereon in a uniform layer ½″ in thickness. The bed shall be ruck to a true surface exactly parallel to the top of the finished pavement the following manner:

Wooden strips 4″ wide by ¼″ thick, or strips of steel 4″ wide by ⅛ to 3⁄16″ ick, of a convenient length for handling, shall be carefully set from curb curb to the exact crown of the pavement and imbedded throughout their ngth in the mortar, so that the top surface of the strips shall be below the ade of the finished pavement by an amount equal to the thickness of the ocks and not less, on the average, than ½″ above the concrete. An ironod straight-edge or striker shall be drawn on two sets of these strips, set as ove described, to strike the mortar bed to a true and even surface. The ortar bed shall be showered with fresh mortar and struck off as many nes as is necessary to produce a uniformly dense bed, free from depressions porous spots. Special care shall be exercised to produce a bed of uniform nsity. As soon as the mortar bed has been struck off, one set of strips all be taken up and the trench carefully filled with mortar so that it will ve the same height and density as the adjacent mortar.

In the case of car tracks, a template to run on the rails shall be used to rike the mortar bed to the required grade between the rails.

19. **Laying the Blocks.**—Upon the mortar cushion prepared as described ove, the blocks shall be immediately laid with close joints and uniform top rface.

The blocks shall be laid by the pavers standing upon the blocks already d and not upon the bed of mortar, and shall be laid at right angles to the is of the pavement with such crown as is shown on the plans, and in such a anner that all longitudinal joints shall be broken by a lap of approximately . The blocks shall be laid so as to make the lateral joints as tight as ssible, consistent with keeping a good alignment across the pavement, and ere possible the longitudinal joints shall be immediately closed by pressing ch course in the direction of its length with a lever.

After the blocks are laid, any irregularities in the surface of the pavement all be corrected and the pavement immediately covered with clean, dry nd, all of which shall pass a 10-mesh sieve. The sand shall be spread over surface and swept into the joints and shall be allowed to remain on pavement not less than 30 days, or until such time as the action of the ffic on the pavement shall have thoroughly ground the sand into all the nts.

20. **Opening to Traffic.**—After the pavement is laid and sanded, it shall be tected from all vehicle traffic for a period of at least 7 days and for a ger period if directed by the engineer.

21. Measurement and Payment.—Payment for asphalt-block wear surfaces shall include the cost of furnishing all materials, equipment, to and labor necessary for the satisfactory completion of the work. Paym will be made on the basis of the number of square yards of wearing surf complete in place.

STATE HIGHWAY DEPARTMENT OF TEXAS

Item 84. Culverts and Retaining Walls

84.1. Description.—All concrete and masonry culverts, all pipe culve headwalls, and retaining walls shall be built as indicated on the plans, c forming to line, grade, dimensions, and design shown, and in accorda with the specifications for Concrete, Masonry, and Pipe of the seve varieties, and other pay items which are to constitute the complete structu

84.2. Materials and material requirements shall be as prescribed for several pay items involved.

84.3. Construction Methods.—All foundations shall be inspected a approved by the engineer previous to placing any masonry of footing. excavations shall be carried to depth of foundation materials satisfact to the engineer regardless of the elevations shown on the plans, and uns able material shall be replaced with approved material if required. rock bottom is secured, the excavation shall be done in such a man as to allow the solid rock to be exposed and prepared in horizontal beds receiving the masonry. All loose and disintegrated rock shall be remov

84.4. Pipe culverts under the roadbed shall be so placed that the m mum distance from finished grade of roadway to the top of pipe shall b provided in the following table:

Table of Minimum Depths of Good Fill or Ballast Over Pip Culverts

(On center line of roadway *C*, and outer edge of shoulder *S*)

Inside diameter	Cast iron		Vitrified clay and corrugated galvanized metal		Concrete		Inside diamet
	C	*S*	*C*	*S*	*C*	*S*	
12″	1′ 0″	8″	1′ 6″	1′ 0″	1′ 0″	8″	12″
14″	1′ 0″	...	...	...	...	...	14″
15″	...	...	1′ 6″	1′ 0″	1′ 0″	...	15″
16″	1′ 0″	8″	...	...	...	...	16″
18″	1′ 0″	8″	1′ 6″	1′ 0″	1′ 0″	8″	18″
24″	1′ 0″	8″	2′ 0″	1′ 0″	1′ 0″	8″	24″
30″	1′ 3″	8″	2′ 6″	1′ 0″	1′ 3″	8″	30″
36″	1′ 6″	8″	3′ 0″	1′ 0″	1′ 6″	8″	36″
42″	1′ 9″	8″	...	...	...	...	42″
48″	2′ 0″	8″	...	...	...	...	48″

Note.—If the material in the fill contains much clay, silt, or loam, incr the above minimum by 4″.

84.5. When pipe is of the bell-and-spigot type, the bell end of the p shall be laid up grade and all joints shall be made water tight with 1 t Portland-cement mortar. Before succeeding sections of pipe are laid, lower portion of the hub of the preceding pipe shall be plastered on inside with cement mortar of sufficient thickness to bring the inner surfa of the abutting pipes even. After the pipe is laid, the remainder of joint shall be filled with similar material, and sufficient additional mate shall be used to form a bead around the joint. The inside of the joint s be wiped and finished smooth. After initial set, the cement on the o side shall be protected from the air and sun with an earth covering. bottom of the trench shall be so shaped as to support each sectior the pipe the full length of the body and shall have depressions cut to t

the bell of the pipe. Wherever solid rock occurs in a culvert trench, it shall be excavated to a depth of at least 6″ below the pipe and the space thus made refilled with selected fine material. In like manner, earthy material that is not sufficiently firm to support the pipe uniformly shall be excavated and replaced by selected fine material. In refilling the pipe trench the material for backfill shall be free from large stones for a depth of 9″ around the pipe, and shall be placed carefully under and around the pipe and tamped to give the pipe a uniform bearing throughout. The ends of all pipe culverts shall be protected by concrete or masonry headwalls unless otherwise ordered by the engineer.

84.6. **Method of Measurement.**—The quantities of the various pay items which constitute the completed and accepted structures shall be measured for payment according to the plans and specifications for the several items. Only accepted work shall be included and the dimensions used shall be the neat dimensions shown on the plans or ordered in writing.

84.7. **Basis of Payment.**—The measured quantities, as provided above, shall be paid for at the contract unit prices bid for the several items, which prices shall be full compensation for furnishing, hauling, and placing all material, all labor, equipment, tools, and necessary incidentals. Such payment shall constitute full payment for the completed structure ready for use. Whenever the construction of the new structures involves the removal or demolition of an exisiting structure, unless otherwise expressly provided, such removal or demolition shall not be paid for directly, but shall be considered a subsidiary work pertaining to excavation or to prescribed pay items involved in the work.

Item 91. Cast-iron Pipe

91.1. **Description.**—Under this item cast-iron pipe conforming to these specifications, of the sizes and dimensions shown on the plans, shall be furnished and placed as directed.

91.2. **Materials.**—Cast-iron pipe shall be of good quality, of the bell-and-spigot type, and all pipe shall be made of cast iron of such character as to be strong, tough, of even grain, and soft enough to admit of satisfactory drilling and cutting; the metal shall be made without any admixture of cinder iron and other inferior metal, and the surface of the pipe shall be free from scales, lumps, blisters and holes, and other defects impairing its strength or utility; it shall be solid, round and cast vertical. It shall be in sections not less than 3′ in length and with the inner and outer surfaces true concentric cylinders. It may be plain, smooth, and straight cast-iron water pipe or it may be approved corrugated cast-iron or approved rib cast-iron culvert pipe. Corrugations, when present, shall have a pitch of not more than 3″ and a depth of not less than ½″. The pipe shall be heated to 300°F. and coated inside and outside by dipping in coal-tar pitch or varnish.

91.3. The pipe shall have a minimum thickness and weight as shown in the following tables, and no pipe shall be accepted the weight of which is more than 5% less than the weights given:

Plain Cast-iron Pipe

Inside Diameter, Inches	Minimum Thickness, Inches	Weight per Foot, Pounds
12	⅜	50
16	7/16	75
18	½	85
24	½	145
30	⅝	180
36	11/16	250

Corrugated or Ribbed Cast-iron Pipe

Inside Diameter, Inches	Minimum Thickness, Inches	Weight per Foot, Pounds
16	¼	60
18	¼	65
24	5/16	90
30	5/16	115
36	⅜	135

91.4. The pipe shall have sufficient strength so that when tested with the three-point standard crushing test, as prescribed in the *Bulletin* 1216, it will show a load-supporting capacity in pounds per linear foot of at least $500D$, where D equals the inside diameter of the pipe in feet.

91.5. Pipe weighing 5 % or more less than the required standard weigh shall be rejected.

91.6. Each section of cast-iron pipe shall be coated inside and outsid with coal-tar pitch varnish, to which sufficient linseed oil has been added t make a smooth coat, tough and tenacious when cold, and with no tendenc to scale off.

91.7. **Method of Measurement and Basis of Payment.**—This item sha be paid for at the contract prices bid per linear foot of Cast-iron Pipe (the several sizes measured complete in place, which prices shall be full con pensation for furnishing, hauling, and installing the pipe, for preparation (bed and backfilling, and for all material, equipment, tools, labor, and inc dentals necessary to complete the work, but shall not be payment for excava tion nor for concrete or masonry headwalls.

Item 92. Corrugated Galvanized Metal Pipe

92.1. **Description.**—This item shall consist of furnishing and placir corrugated galvanized metal pipe conforming to these specifications. Tl pipe shall be furnished of the sizes and dimensions required and shall l installed at such places as shown on the plans or as designated by the eng neer in accordance with these specifications, and in conformity with the lin and grades given.

92.2. **Materials.**—Corrugated metal pipe shall be fabricated from corrugat sheets, the base metal of which shall be made by the open-hearth proces The base metal in the finished sheets shall conform to the following chemic requirements:

The total amount of carbon, phosphorus, sulphur, manganese and silic shall not exceed 0.7 %. If the total of these five elements equals or excee 0.20 %, the metal shall contain not less than 0.17 % of copper and not mo than 0.06 % of sulphur. If the total of these five elements is less than 0.20 the presence of copper is optional and sulphur shall not exceed 0.04 %.

Note.—A permissible variation of 0.04 % will be allowed for total impu ties and 0.01 % for sulphur in analysis of finished sheet.

92.3. **Rivets.**—All rivets shall be of the same material as the base met specified for the corrugated sheets. They shall be thoroughly galvaniz or sherardized.

92.4. **Weight Tolerance.**—The average weight per square foot of the c vert sheets, as determined by weighing in lots not exceeding 6000 lb., sh not vary from the theoretical weight by more than 5 % either way for ea lot of one gage or size.

92.5. **Spelter.**—The base metal sheets shall be uniformly galvanized both sides by the hot process. A uniform coating of Prime Western Spel shall be applied at the rate of not less than 2 oz. per square foot of met If the average spelter coating as determined from samples shows less thar oz. of spelter per square foot of metal, or if any one sample shows less th 1.8 oz. of spelter per square foot of metal, the shipment shall be reject Sheets having blister spots, holes, or other imperfections in the galvanizi after corrugating shall be rejected.

92.6. Bidders shall state in the proposal the typical chemical compositi brand of metal, trade name, and name of manufacturer of the material to furnished.

92.7. No metal shall be accepted under these specifications and no bi shall be considered for the materials above described until after the sh manufacturer's certified analysis and manufacturer's guarantee shall ha been passed upon by the engineer and accepted.

92.8. Misbranding, or other misrepresentation, and non-uniformity product shall each be considered a sufficient reason to discontinue the acce ance of any brand under these specifications, and the notice of discontir ance of any brand sent to the sheet manufacturer shall be considered to notice to any culvert companies which handle that particular brand.

92.9. The manufacturer of each brand shall file with the engineer a cert cate setting forth the name or brand of metal to be furnished and a typi analysis showing the percentage of each of the five above-mentioned chemi elements. The certificate shall be sworn to for the manufacturing compa by a person having legal authority to bind the company.

92.10. The manufacturer of the sheets shall submit with the certifi analysis a guarantee providing that all metal furnished shall conform to t certified analysis filed, shall bear a suitable identification brand or ma and shall be replaced without cost to the purchaser when not in conformi with the specified analysis, gage, or spelter coating, and the guarantee sh

be so worded as to remain in effect as long as the manufacturer continues to furnish material.

92.11. No culverts shall be accepted unless the metal is identified by a stamp on each section showing:

1. Name of sheet manufacturer.
2. Name of brand.
3. The gage.

92.12. The identification brands shall be placed on the sheets by the manufacturers of the sheets, in such a way that when rolled into culverts such identification shall appear on the outside of each section of each pipe. Pipe having any section not so stamped shall be promptly rejected.

92.13. Laboratory tests shall follow the methods of the U. S. Department of Agriculture *Bulletin* 1216. The analysis made by the chemists or inspection bureau designated or approved by the engineer shall be taken as final, but before any considerable shipment is rejected, a check analysis shall be made.

92.14. If the engineer so elects, he may have the material inspected at the rolling mill or the culverts inspected in the shop where they are fabricated. He may require a chemical analysis from the mill for any heat and also a physical test of the properties of the metal taken from any heat, to be made by the mill. The inspection both at the mill and at the shop shall be made under the direction of the engineer. The engineer, or his representative, shall have free access to the mill or shop for inspection purposes, and every facility shall be extended to him for this purpose. Any material or pipe included in any shipment which has been rejected at the mill or shop will be considered sufficient cause for the rejection of the entire shipment.

92.15. All rivets shall be driven cold in such a manner that the plates shall be drawn tightly together throughout the entire lap. No rivet shall be closer than twice its diameter from the edge of the metal. All rivets shall have neat, workmanlike, and full hemispherical heads or heads of a form acceptable to the engineer, shall be driven without bending, and shall completely fill the hole. Longitudinal seams of 30 and 36″ pipe shall be double riveted. Circumferential shop-riveted seams shall have a maximum rivet spacing of ″ and shall lap at least one full corrugation, except that six rivets will be sufficient in 12″ pipe.

92.16. If a band is used for end finish, it shall be riveted around the end of the culvert with rivets at intervals of 10″ or less. This band shall be of galvanized metal equivalent in cross-section to ⅜ by 1″ for 16-gage metal, ⅜ by 1½″ for 14-gage and 12-gage metal.

Special Construction

92.17. **Shape.**—Pipe furnished under these specifications shall be of the full-circle riveted type, with lap-joint construction.

92.18. **Minimum Sizes Admitted.**—For farm-entrance crossings, the minimum diameter of pipe shall be 12″. For roadway culverts, the minimum diameter permitted shall be 15″.

92.19. **Dimensions and Weights.**—The length of sheets and widths of lap shall be as shown in the following table. The dimension given in diameter of pipe is nominal.

The gage of the uncoated metal and weight per foot of the finished culvert shall not be less than specified in the table. All gages given are United States Standard Gage (U. S. S. G.) and the maximum variation allowable in any sheet is 5% either way from the theoretical weight. The total weight of any shipment of 100 sheets or more shall not underrun the theoretical weight by more than 2%.

Nominal diameter, inches	Minimum gage U. S. Standard, uncoated metal	Weight per foot, finished culvert, pounds
12	16	10.8
15	16	13.1
18	16	15.7
21	14	22.6
24	14	25.4
30	14	31.9
36	12	52.0

92.20. **Net Length of Culvert Pipe.**—The length of culvert specified sh be the net length of the finished culvert, which does not include any mater used to procure an end finish on the pipe. If the average deficiency length of any shipment of pipe is greater than 1%, the shipment shall rejected.

92.21. **Lengths of Sections.**—All pipe shall be furnished in the lengt ordered, except that pipe for culverts 26′ or more in length may be furnish in sections not less than 12′ in length. Where bands or couplings a required, a separate unit price shall be submitted for each size necessa such price to cover material and installation. For small shipments involvi less than carload lots, the above requirements may be modified by writt authorization from the engineer.

92.22. **Corrugations.**—Corrugations shall be not less than 2¼ nor mo than 2¾″ center to center. The corrugations shall have a depth of not l than ½″.

92.23. Field joints shall be made with bands of the same material as t culvert, and shall be not less than 7½″ wide, so constructed as to lap equal portion of each of the culvert sections to be connected. Such bar shall be connected at the ends by angles having minimum dimensions 1½ by 1½ by ⅛″, and of length equal to full width of band, or by otl approved connections of suitable strength. Each connection shall be f tened by at least two bolts not less than ½″ in diameter. All such conn tions shall be made of galvanized metal of the same quality as the b metal in the culvert.

92.24. It is the essence of these specifications that, in addition to co pliance with the details of construction, the completed pipe shall show ca ful, finished workmanship in all particulars.

92.25. Culvert pipe on which the spelter coating has been bruised or brol either in the shop or in shipping, or which shows defective workmansh shall be rejected. This requirement shall apply not only to the individ pipe but to the shipment on any contract as a whole. Among others, following defects are specified as constituting poor workmanship, and presence of any or all of them in any individual culvert pipe or, in gene in any shipment, shall constitute sufficient cause for rejection:

Uneven laps.
Elliptical shaping.
Variation from a straight center line.
Ragged or diagonal sheared edges.
Loose, unevenly lined or spaced rivets.
Poorly formed rivet heads.
Unfinished ends.
Illegible brands.
Lack of rigidity.
Bruised, scaled or broken spelter coating.
Dents or bends in the metal itself.

92.26. The field inspection shall be made by the engineer, who shall furnished by the contractor with an itemized statement of the sizes a lengths of culvert pipe in each shipment. This inspection shall include examination of the culvert pipe for deficiencies in lengths of sheets us nominal specified diameter, net length of finished culvert pipe, and a evidence of poor workmanship as outlined above. The inspection n include the taking of samples for chemical analysis and determinatio weight of spelter coating. The inspection shall be made promptly u notification by the contractor of the arrival of the material.

92.27. The pipe making up the shipment shall fully meet the requireme of these specifications, and if 50 % of the pipe in any shipment fails to m these requirements, the entire shipment may be rejected.

92.28. When samples are taken for chemical analysis and determinat of weight of spelter coating, at least one sample from which a specimen 2 square may be prepared shall be selected from each ten culverts of a shipme and not less than three samples shall represent any one shipment.

92.29. The pipe shall be laid in the trench with the separate sections fir joined together and with outside laps of circumferential joints point up stream and with longitudinal laps on the sides. Any metal in joi which is not thoroughly protected by galvanizing shall be coated wit suitable asphaltum paint.

92.30. **Method of Measurement and Basis of Payment.**—This item sl be paid for at the contract prices bid per linear foot of Corrugated Galvani

Metal Pipe of the several sizes measured complete in place, which price shall e full compensation for furnishing, hauling, and installing the pipe, for reparation of bed and backfilling, and for all material, equipment, tools, ıbor, and incidentals, but shall not be payment for excavation nor for oncrete or masonry headwall.

Item 93. Vitrified Clay Pipe

93.1. **Description.**—Under this item vitrified clay pipe conforming to these pecifications, of the sizes and dimensions shown on the plans, shall be ırnished and placed as directed.

93.2. **Materials and Manufacture.**—Vitrified clay pipe shall be of the hub- nd spigot type, of first quality, sound, thoroughly and perfectly burned, ithout warps, cracks, or other imperfections, and shall be fully and smoothly lazed over the entire inner and outer surfaces, except that the inside of the ub and the outside of the spigot may be unglazed for two-thirds of the depth f the hub. On all other portions of the pipe, the glazing shall completely over and form an integral part of the pipe body. If glazed, the inside of ie hub and the outside of the spigot shall be scored in three parallel lines xtending completely around the circumference. This pipe shall be manu- ıctured of a suitable temperature to secure a tough, vitreous material hich, when broken, shall show a tense and solid body, without detrimental acks or laminations. It shall be of such toughness that it may be cut with chisel and hammer, and when struck with a hammer shall give a metallic ng.

93.3. The pipe shall have sufficient strength so that when tested with the ıree-point standard crushing test, as prescribed in the U. S. Department of griculture *Bulletin* 1216, it will show a load-supporting capacity in pounds er linear foot of at least 1500D, where D equals the inside diameter of the ipe in feet.

93.4. The minimum length of sections, thickness, and the depth of hub ıall be as follows:

Size, inches	Minimum length, feet	Thickness, inches	Depth of hub, inches
12	2	1	3
15	2	1¼	3
18	2	1½	3¼
20	2	1⅔	3¼
22	2	1⅚	3¾
24	2	2	4
27	2½	2¼	4
30	2½	2½	4
33	2½	2⅝	5
36	2½	2¾	5
42	2½	3½	5

93.5. **Method of Measurement and Basis of Payment.**—This item shall be aid for at the contract prices bid per linear foot of Vitrified Clay Pipe of ie several sizes measured complete in place, which prices shall be full com- ensation for furnishing, hauling, and installing the pipe, for preparation of ed and backfilling, and for all material, equipment, tools, labor, and ıcidentals necessary to complete the work, but shall not be payment for xcavation or for concrete or masonry headwalls.

Item 94. Relaying Culvert Pipe

94.1. **Description.**—This item shall consist of the careful removal and reserving of pipe from existing pipe culverts as ordered and relaying the ıme as shown on the plans or as designated by the engineer in accordance ıth these specifications for the type of pipe involved and in conformity ith the lines and grades given.

94.2. **Method of Measurement.**—This item shall be measured by the ctual number of linear feet of pipe complete in place as required.

94.3. **Basis of Payment.**—This item measured as provided above shall be aid for at the contract unit price bid per linear foot for Relaying Culvert

Pipe 18″ diameter and under or Relaying Culvert Pipe over 18″ diamet as the case may be, which price shall be full compensation for the remov preservation, and relaying of the pipe, all new material necessary exce pipe, all labor, equipment, tools, and incidentals necessary to complete t work, but shall not be payment for excavation, nor for concrete or masor headwalls.

Item 101. Sodding

101.1. **Description.**—This item shall consist of providing and planti approved live sod on earth slopes or shoulders, when and as directed protection against erosion.

101.2. The sods shall be of suitable size, variety, and character for t purpose selected and for the soil upon which they are to be planted, vigorous and hardy growth, and approved by the engineer.

101.3. On embankments constructed on soil which is easily eroded or sections subject to overflow, and where climatic conditions are favorable the easy rooting of Bermuda Grass, Rescue Grass, Bur Clover, or Japan Clover and if in the opinion of the engineer it is necessary, the contractor sh provide and plant as directed, such sods, or tufts of some suitable grass.

101.4. Where sodding is to be done, tufts of suitable grass shall be pla on slope just underneath the shoulder line so as to form one continuous st of turf 3″ wide and on remainder of slope and upon shoulders similar tu of grass about 3″ in diameter shall be spaced approximately 12″ cente center in rows. Sodding shall be done at such times as the engineer n direct and in such manner that the grass will at once take root.

101.5. **Basis of Payment.**—Sodding completed and accepted by engineer will be paid for at the contract unit price bid per 100 lin. ft. roadway sodded on both sides to the width required by the engineer, wh price shall be full compensation for furnishing and planting the sod, labor, equipment, tools, and incidentals necessary to complete the wo The average width of sodding for the unit price bid shall be construed mean an average width of not over 30′.

PART IV

GENERAL TABLES AND FORMULÆ

Conversion Table

inear Units

Old Surveyors' Units

1 link	=	7.92 in.		
100 links	=	1 chain	=	66 ft.
25 links	=	1 rod	=	16.5 ft.

Ordinary Measure

12 in.	=	1 ft.
3 ft.	=	1 yd.
5280 ft.	=	1 mile

quare Units

1 sq. ft.	=	144 sq. in.
1 sq. yd.	=	9 sq. ft.
	=	1296 sq. in.
1 acre	=	43,560 sq. ft.
	=	4840 sq. yds.
1 sq. mile	=	27,878,400 sq. ft.
	=	3,097,600 sq. yds.
	=	640 acres

'olume Units

1 cu. ft.	=	1728 cu. in.
	=	7.4805 ordinary gal.
	=	6.232 Imperial gal.
1 cu. yd.	=	27 cu. ft.
	=	46,656 cu. in.
1 ordinary gal.	=	231 cu. in.
1 Imperial gal.	=	277 cu. in.
1 barrel	=	31.5 gal.
	=	4.21 cu. ft.

'eight Units

1 pound	=	16 ounces
1 ordinary ton	=	2000 pounds
1 long ton	=	2240 pounds

'emperature Units

reezing point of water	=	32° Fahrenheit
	=	0° Centigrade
oiling point of water at normal air pressure	=	212° Fahrenheit
	=	100° Centigrade
degree Fahrenheit	=	0.5556 degree Centigrade
degree Centigrade	=	1.8 degrees Fahrenheit

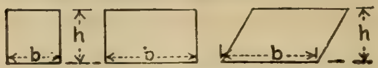
Table of Equivalents of Inches and Fractions of Inches
Decimals of a Foot

In.	0 In.	1 In.	2 In.	3 In.	4 In.	5 In.
		.0833	.1667	.2500	.3333	.4167
1/32	.0026	.0859	.1693	.2526	.3359	.4193
1/16	.0052	.0885	.1719	.2552	.3385	.4219
3/32	.0078	.0911	.1745	.2578	.3411	.4245
1/8	.0104	.0938	.1771	.2604	.3438	.4271
5/32	.0130	.0964	.1797	.2630	.3464	.4297
3/16	.0156	.0990	.1823	.2656	.3490	.4323
7/32	.0182	.1016	.1849	.2682	.3516	.4349
1/4	.0208	.1042	.1875	.2708	.3542	.4375
9/32	.0234	.1068	.1901	.2734	.3568	.4401
5/16	.0260	.1094	.1927	.2760	.3594	.4427
11/32	.0286	.1120	.1953	.2786	.3620	.4453
3/8	.0313	.1146	.1979	.2813	.3646	.4479
13/32	.0339	.1172	.2005	.2839	.3672	.4505
7/16	.0365	.1198	.2031	.2865	.3698	.4531
15/32	.0391	.1224	.2057	.2891	.3724	.4557
1/2	.0417	.1253	.2083	.2917	.3750	.4583
17/32	.0443	.1276	.2091	.2943	.3776	.4609
9/16	.0469	.1302	.2135	.2969	.3802	.4635
19/32	.0495	.1328	.2161	.2995	.3828	.4661
5/8	.0521	.1354	.2188	.3021	.3854	.4688
21/32	.0547	.1380	.2214	.3047	.3880	.4714
11/16	.0573	.1406	.2240	.3073	.3906	.4740
23/32	.0599	.1432	.2266	.3099	.3932	.4766
3/4	.0625	.1458	.2292	.3125	.3958	.4792
25/32	.0651	.1484	.2318	.3151	.3984	.4818
13/16	.0677	.1510	.2344	.3177	.4010	.4844
27/32	.0703	.1536	.2370	.3203	.4036	.4870
7/8	.0729	.1563	.2396	.3229	.4063	.4896
29/32	.0755	.1589	.2422	.3255	.4089	.4922
15/16	.0781	.1615	.2448	.3281	.4115	.4948
31/32	.0807	.1641	.2474	.3307	.4141	.4974

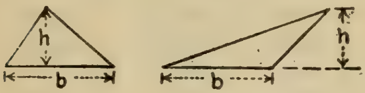
QUIVALENTS OF INCHES AND FRACTIONS OF INCHES IN DECIMALS OF A FOOT

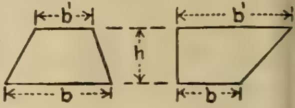
n.	6 In.	7 In.	8 In.	9 In.	10 In.	11 In.
	.5000	.5833	.6667	.7500	.8333	.9167
	.5026	.5859	.6693	.7526	.8359	.9193
	.5052	.5885	.6719	.7552	.8385	.9219
	.5078	.5911	.6745	.7578	.8411	.9245
	.5104	.5938	.6771	.7604	.8438	.9271
	.5130	.5964	.6797	.7630	.8464	.9297
	.5156	.5990	.6823	.7656	.8490	.9323
	.5182	.6016	.6849	.7682	.8516	.9349
	.5208	.6042	.6875	.7708	.8542	.9375
	.5234	.6068	.6901	.7734	.8568	.9401
	.5260	.6094	.6927	.7760	.8594	.9427
	.5286	.6120	.6953	.7786	.8620	.9453
	.5313	.6146	.6979	.7813	.8646	.9479
	.5339	.6172	.7005	.7839	.8672	.9505
	.5365	.6198	.7031	.7865	.8698	.9531
	.5391	.6224	.7057	.7891	.8724	.9557
	.5417	.6250	.7083	.7917	.8750	.9583
	.5443	.6276	.7109	.7943	.8776	.9609
	.5469	.6302	.7135	.7969	.8802	.9635
	.5495	.6328	.7161	.7995	.8828	.9661
	.5521	.6354	.7188	.8021	.8854	.9688
	.5547	.6380	.7214	.8047	.8880	.9714
	.5573	.6406	.7240	.8073	.8906	.9740
	.5599	.6432	.7266	.8099	.8932	.9766
	.5625	.6458	.7292	.8125	.8958	.9792
	.5651	.6484	.7318	.8151	.8984	.9818
	.5677	.6510	.7344	.8177	.9010	.9844
	.5703	.6536	.7370	.8203	.9036	.9870
	.5729	.6563	.7396	.8229	.9063	.9896
	.5755	.6589	.7422	.8255	.9089	.9922
	.5781	.6615	.7448	.8281	.9115	.9948
	.5807	.6641	.7474	.8307	.9141	.9974

TABLE OF AREAS AND VOLUMES

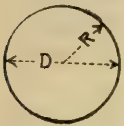


Squares, Rectangles, and Parallelograms. Area $= bh$





Triangles Area $= \frac{1}{2}\, bh$ *Trapezoids* Area $= \dfrac{b + b'}{2}$

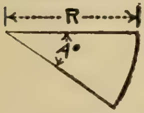


Circles

$$\text{Area} = \pi R^2 = \frac{\pi D^2}{4}$$

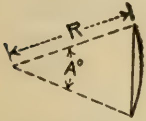
Circumference of Circle $= 2\,\pi R = \pi D$

Commonly used value of $\pi = 3.1416$



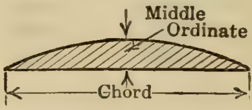
Sector of Circle

$$\text{Area} = \pi R^2 \frac{A^\circ}{360^\circ}$$



Segment of a Circle

$$\text{Area} = \left(\pi R^2 \frac{A^\circ}{360^\circ}\right) - \left(\left(R \sin \frac{A}{2}\right)\left(R \cos \frac{A}{2}\right)\right)$$



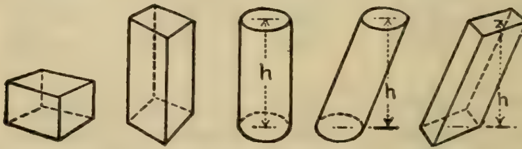
Area of Parabolic Segment

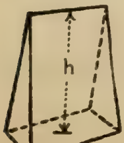
Area $= \frac{2}{3}$ Middle Ordinate $\times$ Chord.

Volumes

Cubes, Rectangular Prisms, Parallelopipeds, Cylinders, etc. solids having parallel bases and a constant cross-section.

Volume = area of base $\times$ perpendicular height between planes of the bases.



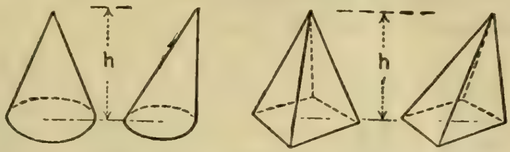


Wedges. Having parallel ends.

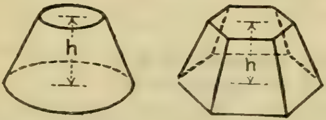
Volume = area of base $\times$ $\frac{1}{2}$ the height perpen-ular to the plane of the base.

Cones and Pyramids, whether right or oblique, regular or irregular.

Volume = $\frac{1}{3}$ area of the base × height perpendicular to the lane of the base



Frustums of Pyramids or Cones, whether right or oblique, reglar or irregular provided the base and top are parallel.



olume = $\frac{1}{3}$ perpendicular eight between base and top × $\left(\text{area top} + \text{area base} + \sqrt{\text{area top} \times \text{area base}}\right)$

: by the prismoidal formula

Volume = $\frac{1}{6}$ perpendicular height between base and top × $\left(\text{area top} + \text{area base} + 4 \times \text{area of section parallel to and midway between base and top}\right)$

'rismoidal Formula

Trautwine defines a prismoid as a solid having for its ends vo parallel plane figures connected by other plane figures on hich and through every point of which a straight line may be rawn from one of the two parallel ends to the other. These onnecting planes may be parallelograms or not and parallel to ıch other or not. This includes cubes, all parallelopipeds, risms, cylinders, pyramids, cones, and their frustums, provided ıe top and base are parallel and wedges.

The prismoidal formula applies to all these solids either alone : to any form that can be separated into units of the above ›rms.

rismoidal formulæ

$$\text{Volume} = h \times \frac{A + a + 4M}{6}$$

h = perpendicular distance between the parallel ends
A = area of one of the parallel ends
a = area of the other parallel end
M = area of a cross-section midway between and parallel to the two parallel ends

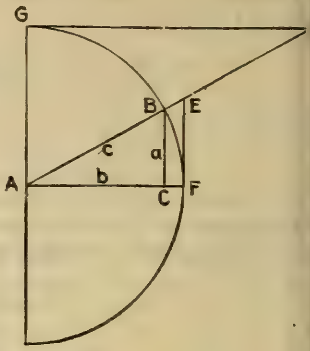
bhere

$$\text{Volume} = \tfrac{4}{3}\pi R^3 = 4.1888\, R^3$$
$$= \tfrac{1}{6}\pi D^3 = 0.5236\, D^3$$

In which R = radius of sphere
D = diameter of sphere

Table of Trigonometric Functions and the Solution c Triangles

In the accompanying figure the trigonometric functions of the angle A between the lines $B\,A$ and $A\,C$ are as follows;



$$\begin{aligned}
\sin A &= B\,C\\
\cos A &= A\,C\\
\tan A &= E\,F\\
\cot A &= G\,H\\
\sec A &= A\,E\\
\operatorname{cosec} A &= A\,H\\
\text{ex-sec } A &= B\,E
\end{aligned}$$

In the right-angled triangle $A\,B\,C$ let a equal the side $B\,C$ opposite the angle A; let b equal the side $A\,C$ opposite the angle B; let equal $A\,B$, the side opposite the angle C.

Let $C = 90°$
The following formulæ apply to right-angled triangles:

Angles. $A + B + C = 180°$

$$A + B = 90°$$
$$A = 90° - B$$
$$B = 90° - A$$

Sides. $a = c \sin A = b \tan$

$$a = \sqrt{(c+b)\ (c -}$$

$$b = c \cos.\ A = \frac{a}{\tan \text{⁄}}$$

$$b = \sqrt{(c+a)\ (c -}$$

$$c = \frac{a}{\sin A} = \frac{b}{\cos A}$$

$$c = \sqrt{a^2 + b^2}$$

$$\sin A = \frac{a}{c}$$

$$\cos A = \frac{b}{c}$$

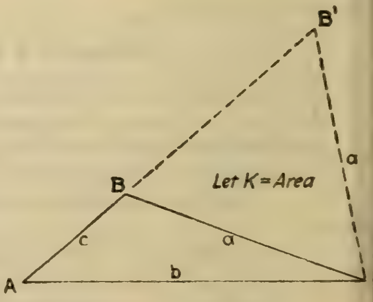
$$\tan A = \frac{a}{b}$$

Area

$$\text{area} = \frac{a\,b}{2}$$

Oblique Triangles.

Note. Where an angle is more than 90° its sine, cosine, and tangent are equal to that of the angle (180° – the angle in question); that is, if the sine of 120° is desired take the sine of (180° – 120°) = 60°.



Given	Desired	Formulæ
A, B, a	C, b	$C = 180 - (A + B);\ \ b = \dfrac{a}{\sin A} \sin B$
	c, K	$c = \dfrac{a}{\sin A} \sin (A + B);\ K = \dfrac{a^2 \sin B \sin C}{2 \sin A}$
A, a, b	B, C	$\sin B = \dfrac{\sin A}{a} b;\ \ C = 180° - (A + B)$
	c	$c = \dfrac{a}{\sin A} \sin C$
		Two solutions are possible with B′ as an acute angle and B as an obtuse angle
C, a, b	$\frac{1}{2}(A+B)$	$\frac{1}{2}(A+B) = 90° - \frac{1}{2} C$
	$\frac{1}{2}(A-B)$	$\tan \frac{1}{2}(A-B) = \dfrac{a-b}{a+b} \quad \tan \frac{1}{2}(A+B)$
	$A\ B$	$A = \frac{1}{2}(A+B) + \frac{1}{2}(A-B)$
		$B = \frac{1}{2}(A+B) - \frac{1}{2}(A-B)$
	c	$c = (a-b) \dfrac{\sin \frac{1}{2}(A+B)}{\sin \frac{1}{2}(A-B)}$
	K	$K = \frac{1}{2} ab \sin C$
a, b, c	B	In the following formula $s = \frac{1}{2}(a + b + c)$
		$\sin \frac{1}{2} B = \sqrt{\dfrac{(s-a)(s-c)}{ac}}$
		$\sin B = \dfrac{2\sqrt{s(s-a)(s-b)(s-c)}}{ac}$
	K	$K = \sqrt{s(s-a)(s-b)(s-c)}$

Table of Squares, Cubes, Square Roots, Cube Roots, Circumferences and Circular Areas of Nos. from 1 to 520

No.	Square	Cube	Sq. Root	Cube Root	Circle Circum.	Circle Area
1	1	1	1.0000	1.0000	3.142	0.785
2	4	8	1.4142	1.2599	6.283	3.141
3	9	27	1.7321	1.4422	9.425	7.068
4	16	64	2.0000	1.5874	12.566	12.566
5	25	125	2.2361	1.7100	15.708	19.635
6	36	216	2.4495	1.8171	18.850	28.274
7	49	343	2.6458	1.9129	21.991	38.484
8	64	512	2.8284	2.0000	25.133	50.265
9	81	729	3.0000	2.0801	28.274	63.617
10	100	1000	3.1623	2.1544	31.416	78.539
11	121	1331	3.3166	2.2240	34.558	95.033
12	144	1728	3.4641	2.2894	37.699	113.097
13	169	2197	3.6056	2.3513	40.841	132.732
14	196	2744	3.7417	2.4101	43.982	153.938
15	225	3375	3.8730	2.4662	47.124	176.715
16	256	4096	4.0000	2.5198	50.265	201.062
17	289	4913	4.1231	2.5713	53.407	226.980
18	324	5832	4.2426	2.6207	56.549	254.469
19	361	6859	4.3589	2.6684	59.690	283.529
20	400	8000	4.4721	2.7144	62.832	314.159
21	441	9261	4.5826	2.7589	65.973	346.361
22	484	10648	4.6904	2.8020	69.115	380.133
23	529	12167	4.7958	2.8439	72.257	415.47
24	576	13824	4.8990	2.8845	75.398	452.38
25	625	15625	5.0000	2.9240	78.540	490.874
26	676	17576	5.0990	2.9625	81.681	530.92
27	729	19683	5.1962	3.0000	84.823	572.55
28	784	21952	5.2915	3.0366	87.965	615.75
29	841	24389	5.3852	3.0723	91.106	660.52
30	900	27000	5.4772	3.1072	94.248	706.85
31	961	29791	5.5678	3.1414	90.389	754.76
32	1024	32768	5.6569	3.1748	100.531	804.24
33	1089	35937	5.7446	3.2075	103.673	855.29
34	1156	39304	5.8310	3.2396	106.814	907.92
35	1225	42875	5.9161	3.2711	109.956	962.11
36	1296	46656	6.0000	3.3019	113.097	1017.88
37	1369	50653	6.0828	3.3322	116.239	1075.21
38	1444	54872	6.1644	3.3620	119.381	1134.11
39	1521	59319	6.2450	3.3912	122.522	1194.59
40	1600	64000	6.3246	3.4200	125.660	1256.64

SQUARES, CUBES, SQUARE ROOTS, CUBE ROOTS, CIRCUMFERENCES AND CIRCULAR AREAS OF NOS. FROM 1 TO 520

No.	Square	Cube	Sq. Root	Cube Root	Circle Circum.	Circle Area
41	1681	68921	6.4031	3.4482	128.81	1320.25
42	1764	74088	6.4807	3.4760	131.95	1385.44
43	1849	79507	6.5574	3.5034	135.09	1452.20
44	1936	85184	6.6332	3.5303	138.23	1520.53
45	2025	91125	6.7082	3.5569	141.37	1590.43
46	2116	97336	6.7823	3.5830	144.51	1661.90
47	2209	103823	6.8557	3.6088	147.65	1734.94
48	2304	110592	6.9282	3.6342	150.80	1809.56
49	2401	117649	7.0000	3.6593	153.94	1885.74
50	2500	125000	7.0711	3.6840	157.08	1963.50
51	2601	132651	7.1414	3.7084	160.22	2042.82
52	2704	140608	7.2111	3.7325	163.36	2123.72
53	2809	148877	7.2801	3.7563	166.50	2206.18
54	2916	157464	7.3485	3.7798	169.65	2290.22
55	3025	166375	7.4162	3.8030	172.79	2375.83
56	3136	175616	7.4833	3.8259	175.93	2463.01
57	3249	185193	7.5498	3.8485	179.07	2551.76
58	3364	195112	7.6158	3.8709	182.21	2642.08
59	3481	205379	7.6811	3.8930	185.35	2733.97
60	3600	216000	7.7460	3.9149	188.50	2827.43
61	3721	226981	7.8102	3.9365	191.64	2922.47
62	3844	238328	7.8740	3.9579	194.78	3019.07
63	3969	250047	7.9373	3.9791	197.92	3117.25
64	4096	262144	8.0000	4.0000	201.06	3216.99
65	4225	274625	8.0623	4.0207	204.20	3318.31
66	4356	287496	8.1240	4.0412	207.35	3421.19
67	4489	300763	8.1854	4.0615	210.49	3525.65
68	4624	314432	8.2462	4.0817	213.63	3631.68
69	4761	328509	8.3066	4.1016	216.77	3739.28
70	4900	343000	8.3666	4.1213	219.91	3848.45
71	5041	357911	8.4261	4.1408	223.05	3959.19
72	5184	373248	8.4853	4.1602	226.19	4071.50
73	5329	389017	8.5440	4.1793	229.34	4185.39
74	5476	405224	8.6023	4.1983	232.48	4300.84
75	5625	421875	8.6603	4.2172	235.62	4417.86
76	5776	438976	8.7178	4.2358	238.76	4536.46
77	5929	456533	8.7750	4.2543	241.90	4656.63
78	6084	474552	8.8318	4.2727	245.04	4778.36
79	6241	493039	8.8882	4.2908	248.19	4901.67
80	6400	512000	8.9443	4.3089	251.33	5026.55

Squares, Cubes, Square Roots, Cube Roots, Circumferences and Circular Areas of Nos. from 1 to 520

No.	Square	Cube	Sq. Root	Cube Root	Circle	
					Circum.	Area
81	6561	531441	9.0000	4.3267	254.47	5153.0
82	6724	551368	9.0554	4.3445	257.61	5281.0
83	6889	571787	9.1104	4.3621	260.75	5410.6
84	7056	592704	9.1652	4.3795	263.89	5541.7
85	7225	614125	9.2195	4.3968	267.04	5674.5
86	7396	636056	9.2736	4.4140	270.18	5808.8
87	7569	658503	9.3274	4.4310	273.32	5944.6
88	7744	681472	9.3808	4.4480	276.46	6082.1
89	7921	704969	9.4340	4.4647	279.60	6221.1
90	8100	729000	9.4868	4.4814	282.74	6361.7
91	8281	753571	9.5394	4.4979	285.88	6503.8
92	8464	778688	9.5917	4.5144	289.03	6647.6
93	8649	804357	9.6437	4.5307	292.17	6792.9
94	8836	830584	9.6954	4.5468	295.31	6939.7
95	9025	857375	9.7468	4.5629	298.45	7088.2
96	9216	884736	9.7980	4.5789	301.59	7238.2
97	9409	912673	9.8489	4.5947	304.73	7389.8
98	9604	941192	9.8995	4.6104	307.88	7542.
99	9801	970299	9.9499	4.6261	311.02	7697.
100	10000	1000000	10.0000	4.6416	314.16	7853.
101	10201	1030301	10.0499	4.6570	317.30	8011.
102	10404	1061208	10.0995	4.6723	320.44	8171.
103	10609	1092727	10.1489	4.6875	323.58	8332.
104	10816	1124864	10.1980	4.7027	326.73	8494.
105	11025	1157625	10.2470	4.7177	329.87	8659.
106	11236	1191016	10.2956	4.7326	333.01	8824.
107	11449	1225043	10.3441	4.7475	336.15	8992.
108	11664	1259712	10.3923	4.7622	339.29	9160.
109	11881	1295029	10.4403	4.7769	342.43	9331.
110	12100	1331000	10.4881	4.7914	345.58	9503.
111	12321	1367631	10.5357	4.8059	348.72	9676.
112	12544	1404928	10.5830	4.8203	351.86	9852.
113	12769	1442897	10.6301	4.8346	355.00	10028.
114	12996	1481544	10.6771	4.8488	358.14	10207.
115	13225	1520875	10.7238	4.8629	361.28	10386.
116	13456	1560896	10.7703	4.8770	364.42	10568.
117	13689	1601613	10.8167	4.8910	367.57	10751.
118	13924	1643032	10.8628	4.9049	370.71	10935.
119	14161	1685159	10.9087	4.9187	373.85	11122.
120	14400	1728000	10.9545	4.9324	376.99	11309.

SQUARES, CUBES, SQUARE ROOTS, CUBE ROOTS, CIRCUMFERENCES AND CIRCULAR AREAS OF NOS. FROM 1 TO 520

No.	Square	Cube	Sq. Root	Cube Root	Circle	
					Circum.	Area
121	14641	1771561	11.0000	4.9461	380.13	11499.0
122	14884	1815848	11.0454	4.9597	383.27	11689.9
123	15129	1860867	11.0905	4.9732	386.42	11882.3
124	15376	1906624	11.1355	4.9866	389.56	12076.3
125	15625	1953125	11.1803	5.0000	392.70	12271.8
126	15876	2000376	11.2250	5.0133	395.84	12469.0
127	16129	2048383	11.2694	5.0265	398.98	12667.7
128	16384	2097152	11.3137	5.0397	402.12	12868.0
129	16641	2146689	11.3578	5.0528	405.27	13069.8
130	16900	2197000	11.4018	5.0658	408.41	13273.2
131	17161	2248091	11.4455	5.0788	411.55	13478.2
132	17424	2299968	11.4891	5.0916	414.69	13684.8
133	17689	2352637	11.5326	5.1045	417.83	13892.9
134	17956	2406104	11.5758	5.1172	420.97	14102.6
135	18225	2460375	11.6190	5.1299	424.12	14313.9
136	18496	2515456	11.6619	5.1426	427.26	14526.7
137	18769	2571353	11.7047	5.1551	430.40	14741.1
138	19044	2628072	11.7473	5.1676	433.54	14957.1
139	19321	2685619	11.7898	5.1801	436.68	15174.7
140	19600	2744000	11.8322	5.1925	439.82	15393.8
141	19881	2803221	11.8743	5.2048	442.96	15614.5
142	20164	2863288	11.9164	5.2171	446.11	15836.8
143	20449	2924207	11.9583	5.2293	449.25	16060.6
144	20736	2985984	12.0000	5.2415	452.39	16286.0
145	21025	3048625	12.0416	5.2536	455.53	16513.0
146	21316	3112136	12.0830	5.2656	458.67	16741.5
147	21609	3176523	12.1244	5.2776	461.81	16971.7
148	21904	3241792	12.1655	5.2896	464.96	17203.4
149	22201	3307949	12.2066	5.3015	468.10	17436.6
150	22500	3375000	12.2474	5.3133	471.24	17671.5
151	22801	3442951	12.2882	5.3251	474.38	17907.9
152	23104	3511808	12.3288	5.3368	477.52	18145.8
153	23409	3581577	12.3693	5.3485	480.66	18385.4
154	23716	3652264	12.4097	5.3601	483.81	18626.5
155	24025	3723875	12.4499	5.3717	486.95	18869.2
156	24336	3796416	12.4900	5.3832	490.09	19113.4
157	24649	3869893	12.5300	5.3947	493.23	19359.3
158	24964	3944312	12.5698	5.4061	496.37	19606.7
159	25281	4019679	12.6095	5.4175	499.51	19855.7
160	25600	4096000	12.6491	5.4288	502.65	20106.2

Squares, Cubes, Square Roots, Cube Roots, Circumference and Circular Areas of Nos. from 1 to 520

No.	Square	Cube	Sq. Root	Cube Root	Circle	
					Circum.	Area
161	25921	4173281	12.6886	5.4401	505.80	20358.3
162	26244	4251528	12.7279	5.4514	508.94	20612.0
163	26569	4330747	12.7671	5.4626	512.08	20867.2
164	26896	4410944	12.8062	5.4737	515.22	21124.1
165	27225	4492125	12.8452	5.4848	518.36	21382.5
166	27556	4574296	12.8841	5.4959	521.50	21642.4
167	27889	4657463	12.9228	5.5069	524.65	21904.0
168	28224	4741632	12.9615	5.5178	527.79	22167.1
169	28561	4826809	13.0000	5.5288	530.93	22431.8
170	28900	4913000	13.0384	5.5397	534.07	22698.0
171	29241	5000211	13.0767	5.5505	537.21	22965.8
172	29584	5088448	13.1149	5.5613	540.35	23235.
173	29929	5177717	13.1529	5.5721	543.50	23506.
174	30276	5268024	13.1909	5.5828	546.64	23778.
175	30625	5359375	13.2288	5.5934	549.78	24052.
176	30976	5451776	13.2665	5.6041	552.92	24328.
177	31329	5545233	13.3041	5.6147	556.06	24605.
178	31684	5639752	13.3417	5.6252	559.20	24884.
179	32041	5735339	13.3791	5.6357	562.35	25164.
180	32400	5832000	13.4164	5.6462	565.49	25446.
181	32761	5929741	13.4536	5.6567	568.63	25730.
182	33124	6028568	13.4907	5.6671	571.77	26015.
183	33489	6128487	13.5277	5.6774	574.91	26302.
184	33856	6229504	13.5647	5.6877	578.05	26590.
185	34225	6331625	13.6015	5.6980	581.19	26880.
186	34596	6434856	13.6382	5.7083	584.34	27171.
187	34969	6539203	13.6748	5.7185	587.48	27464.
188	35344	6644672	13.7113	5.7287	590.62	27759.
189	35721	6751269	13.7477	5.7388	593.76	28055.
190	36100	6859000	15.7840	5.7489	596.90	28352.
191	36481	6967871	13.8203	5.7590	600.04	28652.
192	36864	7077888	13.8564	5.7690	603.19	28952.
193	37249	7189057	13.8924	5.7790	606.33	29255.
194	37636	7301384	13.9284	5.7890	609.47	29559.
195	38025	7414875	13.9642	5.7989	612.61	29864.
196	38416	7529536	14.0000	5.8088	615.75	30171.
197	38809	7645373	14.0357	5.8186	618.89	30480.
198	39204	7762392	14.0712	5.8285	622.04	30790.
199	39601	7880599	14.1067	5.8383	625.18	31102.
200	40000	8000000	14.1421	5.8480	628.32	31415.

Squares, Cubes, Square Roots, Cube Roots, Circumferences and Circular Areas of Nos. from 1 to 520

No.	Square	Cube	Sq. Root	Cube Root	Circle Circum.	Circle Area
201	40401	8120601	14.1774	5.8578	631.46	31730.9
202	40804	8242408	14.2127	5.8675	634.60	32047.4
203	41209	8365427	14.2478	5.8771	637.74	32365.5
204	41616	8489664	14.2829	5.8868	640.89	32685.1
205	42025	8615125	14.3178	5.8964	644.03	33006.4
206	42436	8741816	14.3527	5.9059	647.17	33329.2
207	42849	8869743	14.3875	5.9155	650.31	33653.5
208	43264	8998912	14.4222	5.9250	653.45	33979.5
209	43681	9129329	14.4568	5.9345	656.59	34307.0
210	44100	9261000	14.4914	5.9439	659.73	34636.1
211	44521	9393931	14.5258	5.9533	662.88	34966.7
212	44944	9528128	14.5602	5.9627	666.02	35298.9
213	45369	9663597	14.5945	5.9721	669.16	35632.7
214	45796	9800344	14.6287	5.9814	672.30	35968.1
215	46225	9938375	14.6629	5.9907	675.44	36305.0
216	46656	10077696	14.6969	6.0000	678.58	36643.5
217	47089	10218313	14.7309	6.0092	681.73	36983.6
218	47524	10360232	14.7648	6.0185	684.87	37325.3
219	47961	10503459	14.7986	6.0277	688.01	37668.5
220	48400	10648000	14.8324	6.0368	691.15	38013.3
221	48841	10793861	14.8661	6.0459	694.29	38359.6
222	49284	10941048	14.8997	6.0550	697.43	38707.6
223	49729	11089567	14.9332	6.0641	700.58	39057.1
224	50176	11239424	14.9666	6.0732	703.72	39408.1
225	50625	11390625	15.0000	6.0822	706.86	39760.8
226	51076	11543176	15.0333	6.0912	710.00	40115.0
227	51529	11697083	15.0665	6.1002	713.14	40470.8
228	51984	11852352	15.0997	6.1091	716.28	40828.1
229	52441	12008989	15.1327	6.1180	719.42	41187.1
230	52900	12167000	15.1658	6.1269	722.57	41547.6
231	53361	12326391	15.1987	6.1358	725.71	41909.6
232	53824	12487168	15.2315	6.1446	728.85	42273.3
233	54289	12649337	15.2643	6.1534	731.99	42638.5
234	54756	12812904	15.2971	6.1622	735.13	43005.3
235	55225	12977875	15.3297	6.1710	738.27	43373.6
236	55696	13144256	15.3623	6.1797	741.42	43743.5
237	56169	13312053	15.3948	6.1885	744.56	44115.0
238	56644	13481272	15.4272	6.1972	747.70	44488.1
239	57121	13651919	15.4596	6.2058	750.84	44862.7
240	57600	13824000	15.4919	6.2145	753.98	45238.9

Squares, Cubes, Square Roots, Cube Roots, Circumference and Circular Areas of Nos. from 1 to 520

No.	Square	Cube	Sq. Root	Cube Root	Circle Circum.	Circle Area
241	58081	13997521	15.5242	6.2231	757.12	45616.7
242	58564	14172488	15.5563	6.2317	760.27	45996.1
243	59049	14348907	15.5885	6.2403	763.41	46377.
244	59536	14526784	15.6205	6.2488	766.55	46759.5
245	60025	14706125	15.6525	6.2573	769.69	47143.
246	60516	14886936	15.6844	6.2658	772.83	47529.
247	61009	15069223	15.7162	6.2743	775.97	47916.
248	61504	15252992	15.7480	6.2828	779.12	48305.
249	62001	15438249	15.7797	6.2912	782.26	48695.
250	62500	15625000	15,8114	6.2996	785.40	49087.
251	63001	15813251	15.8430	6.3080	788.54	49480.
252	63504	16003008	15.8745	6.3164	791.68	49875.
253	64009	16194277	15.9060	6.3247	794.82	50272.
254	64516	16387064	15.9374	6.3330	797.96	50670.
255	65025	16581375	15.9687	6.3413	801.11	51070.
256	65536	16777216	16.0000	6.3496	804.25	51471.
257	66049	16974593	16.0312	6.3579	807.39	51874.
258	66564	17173512	16.0624	6.3661	810.53	52279.
259	67081	17373979	16.0935	6.3743	813.67	52685.
260	67600	17576000	16.1245	6.3825	816.81	53092.
261	68121	17779581	16.1555	6.3907	819.96	53502.
262	68644	17984728	16.1864	6.3988	823.10	53912.
263	69169	18191447	16.2173	6.4070	826.24	54325.
264	69696	18399744	16.2481	6.4151	829.38	54739.
265	70225	18609625	16.2788	6.4232	832.52	55154.
266	70756	18821096	16.3095	6.4312	835.66	55571.
267	71289	19034163	16.3401	6.4393	838.81	55990.
268	71824	19248832	16.3707	6.4473	841.95	56410.
269	72361	19465109	16.4012	6.4553	845.09	56832.
270	72900	19683000	16.4317	6.4633	848.23	57255.
271	73441	19902511	16.4621	6.4713	851.37	57680.
272	73984	20123648	16.4924	6.4792	854.51	58106.
273	74529	20346417	16.5227	6.4872	857.66	58534.
274	75076	20570824	16.5529	6.4951	860.80	58964.
275	75625	20796875	16.5831	6.5030	863.94	59395.
276	76176	21024576	16.6132	6.5108	867.08	59828.
277	76729	21253933	16.6433	6.5187	870.22	60262.
278	77284	21484952	16.6733	6.5265	873.36	60698.
279	77841	21717639	16.7033	6.5343	876.50	61136.
280	78400	21952000	16.7332	6.5421	879.65	61575.

SQUARES, CUBES, SQUARE ROOTS, CUBE ROOTS, CIRCUMFERENCES AND CIRCULAR AREAS OF NOS. FROM 1 TO 520

No.	Square	Cube	Sq. Root	Cube Root	Circle	
					Circum.	Area
281	78961	22188041	16.7631	6.5499	882.79	62015.8
282	79524	22425768	16.7929	6.5577	885.93	62458.0
283	80089	22665187	16.8226	6.5654	889.07	62901.8
284	80656	22906304	16.8523	6.5731	892.21	63347.1
285	81225	23149125	16.8819	6.5808	895.35	63794.0
286	81796	23393656	16.9115	6.5885	898.50	64242.4
287	82369	23639903	16.9411	6.5962	901.64	64692.5
288	82944	23887872	16.9706	6.6039	904.78	65144.1
289	83521	24137569	17.0000	6.6115	907.92	65597.2
290	84100	24389000	17.0294	6.6191	911.06	66052.0
291	84681	24642171	17.0587	6.6267	914.20	66508.3
292	85264	24897088	17.0880	6.6343	917.35	66966.2
293	85849	25153757	17.1172	6.6419	920.49	67425.6
294	86436	25412184	17.1464	6.6494	923.63	67886.7
295	87025	25672375	17.1756	6.6569	926.77	68349.3
296	87616	25934336	17.2047	6.6644	929.91	68813.5
297	88209	26198073	17.2337	6.6719	933.05	69279.2
298	88804	26463592	17.2627	6.6794	936.19	69746.5
299	89401	26730899	17.2916	6.6869	939.34	70215.4
300	90000	27000000	17.3205	6.6943	942.48	70685.8
301	90601	27270901	17.3494	6.7018	945.62	71157.9
302	91204	27543608	17.3781	6.7092	948.76	71631.5
303	91809	27818127	17.4069	6.7166	951.90	72106.6
304	92416	28094464	17.4356	6.7240	955.04	72583.4
305	93025	28372625	17.4642	6.7313	958.19	73061.7
306	93636	28652616	17.4929	6.7387	961.33	73541.5
307	94249	28934443	17.5214	6.7460	964.47	74023.0
308	94864	29218112	17.5499	6.7533	967.61	74506.0
309	95481	29503629	17.5784	6.7606	970.75	74990.6
310	96100	29791000	17.6068	6.7679	973.89	75476.8
311	96721	30080231	17.6352	6.7752	977.04	75964.5
312	97344	30371328	17.6635	6.7824	980.18	76453.8
313	97969	30664297	17.6918	6.7897	983.32	76944.7
314	98596	30959144	17.7200	6.7969	986.46	77437.1
315	99225	31255875	17.7482	6.8041	989.60	77931.1
316	99856	31554496	17.7764	6.8113	992.74	78426.7
317	100489	31855013	17.8045	6.8185	995.88	78923.9
318	101124	32157432	17.8326	6.8256	999.03	79422.6
319	101761	32461759	17.8606	6.8328	1002.20	79922.9
320	102400	32768000	17.8885	6.8399	1005.30	80424.8

SQUARES, CUBES, SQUARE ROOTS, CUBE ROOTS, CIRCUMFERENCE AND CIRCULAR AREAS OF NOS. FROM 1 TO 520

No.	Square	Cube	Sq. Root	Cube Root	Circle Circum.	Circle Area
321	103041	33076161	17.9165	6.8470	1008.5	80928.2
322	103684	33386248	17.9444	6.8541	1011.6	81433.2
323	104329	33698267	17.9722	6.8612	1014.7	81939.8
324	104976	34012224	18.0000	6.8683	1017.9	82448.0
325	105625	34328125	18.0278	6.8753	1021.0	82957.7
326	106276	34645976	18.0555	6.8824	1024.2	83469.0
327	106929	34965783	18.0831	6.8894	1027.3	83981.8
328	107584	35287552	18.1108	6.8964	1030.4	84496.3
329	108241	35611289	18.1384	6.9034	1033.6	85012.3
330	108900	35937000	18.1659	6.9104	1036.7	85529.9
331	109561	36264691	18.1934	6.9174	1039.9	86049.0
332	110224	36594368	18.2209	6.9244	1043.0	86569.7
333	110889	36926037	18.2483	6.9313	1046.2	87092.0
334	111556	37259704	18.2757	6.9382	1049.3	87615.9
335	112225	37595375	18.3030	6.9451	1052.4	88141.3
336	112896	37933056	18.3303	6.9521	1055.6	88668.3
337	113569	38272753	18.3576	6.9589	1058.7	89196.9
338	114244	38614472	18.3848	6.9658	1061.9	89727.0
339	114921	38958219	18.4120	6.9727	1065.0	90258.7
340	115600	39304000	18.4391	6.9795	1068.1	90792.0
341	116281	39651821	18.4662	6.9864	1071.3	91326.9
342	116964	40001688	18.4932	6.9932	1074.4	91863.3
343	117649	40353607	18.5203	7.0000	1077.6	92401.3
344	118336	40707584	18.5472	7.0068	1080.7	92940.9
345	119025	41063625	18.5742	7.0136	1083.8	93482.0
346	119716	41421736	18.6011	7.0203	1087.0	94024.7
347	120409	41781923	18.6279	7.0271	1090.1	94569.0
348	121104	42144192	18.6548	7.0338	1093.3	95114.9
349	121801	42508549	18.6815	7.0406	1096.4	95662.3
350	122500	42875000	18.7083	7.0473	1099.6	96211.3
351	123201	43243551	18.7350	7.0540	1102.7	96761.8
352	123904	43614208	18.7617	7.0607	1105.8	97314.0
353	124609	43986977	18.7883	7.0674	1109.0	97867.7
354	125316	44361864	18.8149	7.0740	1112.1	98423.0
355	126025	44738875	18.8414	7.0807	1115.3	98979.8
356	126736	45118016	18.8680	7.0873	1118.4	99538.2
357	127449	45499293	18.8944	7.0940	1121.5	100098
358	128164	45882712	18.9209	7.1006	1124.7	100660
359	128881	46268279	18.9473	7.1072	1127.8	101223
360	129600	46656000	18.9737	7.1138	1131.0	101788

SQUARES, CUBES, SQUARE ROOTS, CUBE ROOTS, CIRCUMFERENCES AND CIRCULAR AREAS OF NOS. FROM 1 TO 520

No.	Square	Cube	Sq. Root	Cube Root	Circle	
					Circum.	Area
361	130321	47045881	19.0000	7.1204	1134.1	102354
362	131044	47437928	19.0263	7.1269	1137.3	102922
363	131769	47832147	19.0526	7.1335	1140.4	103491
364	132496	48228544	19.0788	7.1400	1143.5	104062
365	133225	48627125	19.1050	7.1466	1146.7	104635
366	133956	49027896	19.1311	7.1531	1149.8	105209
367	134689	49430863	19.1572	7.1596	1153.0	105785
368	135424	49836032	19.1833	7.1661	1156.1	106362
369	136161	50243409	19.2094	7.1726	1159.2	106941
370	136900	50653000	19.2354	7.1791	1162.4	107521
371	137641	51064811	19.2614	7.1855	1165.5	108103
372	138384	51478848	19.2873	7.1920	1168.7	108687
373	139129	51895117	19.3132	7.1984	1171.8	109272
374	139876	52313624	19.3391	7.2048	1175.0	109858
375	140625	52734375	19.3649	7.2112	1178.1	110447
376	141376	53157376	19.3907	7.2177	1181.2	111036
377	142129	53582633	19.4165	7.2240	1184.4	111628
378	142884	54010152	19.4422	7.2304	1187.5	112221
379	143641	54439939	19.4679	7.2368	1190.7	112815
380	144400	54872000	19.4936	7.2432	1193.8	113411
381	145161	55306341	19.5192	7.2495	1196.9	114009
382	145924	55742968	19.5448	7.2558	1200.1	114608
383	146689	56181887	19.5704	7.2622	1203.2	115209
384	147456	56623104	19.5959	7.2685	1206.4	115812
385	148225	57066625	19.6214	7.2748	1209.5	116416
386	148996	57512456	19.6469	7.2811	1212.7	117021
387	149769	57960603	19.6723	7.2874	1215.8	117628
388	150544	58411072	19.6977	7.2936	1218.9	118237
389	151321	58863869	19.7231	7.2999	1222.1	118847
390	152100	59319000	19.7484	7.3061	1225.2	119459
391	152881	59776471	19.7737	7.3124	1228.4	120072
392	153664	60236288	19.7990	7.3186	1231.5	120687
393	154449	60698457	19.8242	7.3248	1234.6	121304
394	155236	61162984	19.8494	7.3310	1237.8	121922
395	156025	61629875	19.8746	7.3372	1240.9	122542
396	156816	62099136	19.8997	7.3434	1244.1	123163
397	157609	62570773	19.9249	7.3496	1247.2	123786
398	158404	63044792	19.9499	7.3558	1250.4	124410
399	159201	63521199	19.9750	7.3619	1253.5	125036
400	160000	64000000	20.0000	7.3684	1256.6	125664

SQUARES, CUBES, SQUARE ROOTS, CUBE ROOTS, CIRCUMFERENCES, AND CIRCULAR AREAS OF NOS. FROM 1 TO 520

No.	Square	Cube	Sq. Root	Cube Root	Circle	
					Circum.	Area
401	160801	64481201	20.0250	7.3742	1259.8	126293
402	161604	64964808	20.0499	7.3803	1262.9	126923
403	162409	65450827	20.0749	7.3864	1266.1	127556
404	163216	65939264	20.0998	7.3925	1269.2	128190
405	164025	66430125	20.1246	7.3986	1272.3	128825
406	164836	66923416	20.1494	7.4047	1275.5	129462
407	165649	67419143	20.1742	7.4108	1278.6	130100
408	166464	67917312	20.1990	7.4169	1281.8	130741
409	167281	68417929	20.2237	7.4229	1284.9	131382
410	168100	68921000	20.2485	7.4290	1288.1	132025
411	168921	69426531	20.2731	7.4350	1291.2	132670
412	169744	69934528	20.2978	7.4410	1294.3	133317
413	170569	70444997	20.3224	7.4470	1297.5	133965
414	171396	70957944	20.3470	7.4530	1300.6	134614
415	172225	71473375	20.3715	7.4590	1303.8	135265
416	173056	71991296	20.3961	7.4650	1306.9	135918
417	173889	72511713	20.4206	7.4710	1310.0	136572
418	174724	73034632	20.4450	7.4770	1313.2	137228
419	175561	73560059	20.4695	7.4829	1316.3	137885
420	176400	74088000	20.4939	7.4889	1319.5	138544
421	177241	74618461	20.5183	7.4948	1322.6	139205
422	178084	75151448	20.5426	7.5007	1325.8	139867
423	178929	75686967	20.5670	7.5067	1328.9	140531
424	179776	76225024	20.5913	7.5126	1332.0	141196
425	180625	76765625	20.6155	7.5185	1335.2	141863
426	181476	77308776	20.6398	7.5244	1338.3	142531
427	182329	77854483	20.6640	7.5302	1341.5	143201
428	183184	78402752	20.6882	7.5361	1344.6	143872
429	184041	78953589	20.7123	7.5420	1347.7	144545
430	184900	79507000	20.7364	7.5478	1350.9	145220
431	185761	80062991	20.7605	7.5537	1354.0	145896
432	186624	80621568	20.7846	7.5595	1357.2	146574
433	187489	81182737	20.8087	7.5654	1360.3	147254
434	188356	81746504	20.8327	7.5712	1363.5	147934
435	189225	82312875	20.8567	7.5770	1366.6	148617
436	190096	82881856	20.8806	7.5828	1369.7	149301
437	190969	83453453	20.9045	7.5886	1372.9	149987
438	191844	84027672	20.9284	7.5944	1376.0	150674
439	192721	84604519	20.9523	7.6001	1379.2	151363
440	193600	85184000	20.9762	7.6059	1382.3	152053

Squares, Cubes, Square Roots, Cube Roots, Circumferences and Circular Areas of Nos. from 1 to 520

No.	Square	Cube	Sq. Root	Cube Root	Circle	
					Circum.	Area
441	194481	85766121	21.0000	7.6117	1385.4	152745
442	195364	86350888	21.0238	7.6174	1388.6	153439
443	196249	86938307	21.0476	7.6232	1391.7	154134
444	197136	87528384	21.0713	7.6289	1394.9	154830
445	198025	88121125	21.0950	7.6346	1398.0	155528
446	198916	88716536	21.1187	7.6403	1401.2	156228
447	199809	89314623	21.1424	7.6460	1404.3	156930
448	200704	89915392	21.1660	7.6517	1407.4	157633
449	201601	90518849	21.1896	7.6574	1410.6	158337
450	202500	91125000	21.2132	7.6631	1413.7	159043
451	203401	91733851	21.2368	7.6688	1416.9	159751
452	204304	92345408	21.2603	7.6744	1420.0	160460
453	205209	92959677	21.2838	7.6801	1423.1	161171
454	206116	93576664	21.3073	7.6857	1426.3	161883
455	207025	94196375	21.3307	7.6914	1429.4	162597
456	207936	94818816	21.3542	7.6970	1432.6	163313
457	208849	95443993	21.3776	7.7026	1435.7	164030
458	209764	96071912	21.4009	7.7082	1438.9	164748
459	210681	96702579	21.4243	7.7138	1442.0	165468
460	211600	97336000	21.4476	7.7194	1445.1	166190
461	212521	97972181	21.4709	7.7250	1448.3	166914
462	213444	98611128	21.4942	7.7306	1451.4	167639
463	214369	99252847	21.5174	7.7362	1454.6	168365
464	215296	99897344	21.5407	7.7418	1457.7	169093
465	216225	100544625	21.5639	7.7473	1460.8	169823
466	217156	101194696	21.5870	7.7529	1464.0	170554
467	218089	101847563	21.6102	7.7584	1467.1	171287
468	219024	102503232	21.6333	7.7639	1470.3	172021
469	219961	103161709	21.6564	7.7695	1473.4	172757
470	220900	103823000	21.6795	7.7750	1476.5	173494
471	221841	104487111	21.7025	7.7805	1479.7	174234
472	222784	105154048	21.7256	7.7860	1482.8	174974
473	223729	105823817	21.7486	7.7915	1486.0	175716
474	224676	106496424	21.7715	7.7970	1489.1	176460
475	225625	107171875	21.7945	7.8025	1492.3	177205
476	226576	107850176	21.8174	7.8079	1495.4	177952
477	227529	108531333	21.8403	7.8134	1498.5	178701
478	228484	109215352	21.8632	7.8188	1501.7	179451
479	229441	109902239	21.8861	7.8243	1504.8	180203
480	230400	110592000	21.9089	7.8297	1508.0	180956

Squares, Cubes, Square Roots, Cube Roots, Circumference and Circular Areas of Nos. from 1 to 520

No.	Square	Cube	Sq. Root	Cube Root	Circle Circum.	Circle Area
481	231361	111284641	21.9317	7.8352	1511.1	181711
482	232324	111980168	21.9545	7.8406	1514.3	182467
483	233289	112678587	21.9773	7.8460	1517.4	183225
484	234256	113379904	22.0000	7.8514	1520.5	183984
485	235225	114084125	22.0227	7.8568	1523.7	184745
486	236196	114791256	22.0454	7.8622	1526.8	185508
487	237169	115501303	22.0681	7.8676	1530.0	186272
488	238144	116214272	22.0907	7.8730	1533.1	187038
489	239121	116930169	22.1133	7.8784	1536.2	187805
490	240100	117649000	22.1359	7.8837	1539.4	188574
491	241081	118370771	22.1585	7.8891	1542.5	189345
492	242064	119095488	22.1811	7.8944	1545.7	190117
493	243049	119823157	22.2036	7.8998	1548.8	190890
494	244036	120553784	22.2261	7.9051	1551.9	191665
495	245025	121287375	22.2486	7.9105	1555.1	192442
496	246016	122023936	22.2711	7.9158	1558.2	193221
497	247009	122763473	22.2935	7.9211	1561.4	194000
498	248004	123505992	22.3159	7.9264	1564.5	194782
499	249001	124251499	22.3383	7.9317	1567.7	195565
500	250000	125000000	22.3607	7.9370	1570.8	196350
501	251001	125751501	22.3830	7.9423	1573.9	197136
502	252004	126506008	22.4054	7.9476	1577.1	197923
503	253009	127263527	22.4277	7.9528	1580.2	198713
504	254016	128024064	22.4499	7.9581	1583.4	199504
505	255025	128787625	22.4722	7.9634	1586.5	200296
506	256036	129554216	22.4944	7.9686	1589.7	201090
507	257049	130323843	22.5167	7.9739	1592.8	201886
508	258064	131096512	22.5389	7.9791	1595.9	202683
509	259081	131872229	22.5610	7.9843	1599.1	203482
510	260100	132651000	22.5832	7.9896	1602.2	204282
511	261121	133432831	22.6053	7.9948	1605.4	205084
512	262144	134217728	22.6274	8.0000	1608.5	205887
513	263169	135005697	22.6495	8.0052	1611.6	206692
514	264196	135796744	22.6716	8.0104	1614.8	207499
515	265225	136590875	22.6936	8.0156	1617.9	208307
516	266256	137388096	22.7156	8.0208	1621.1	209117
517	267289	138188413	22.7376	8.0260	1624.2	209928
518	268324	138991832	22.7596	8.0311	1627.3	210741
519	269361	139798359	22.7816	8.0363	1630.5	211556
520	270400	140608000	22.8035	8.0415	1633.6	212372

TABLE OF TANGENTS AND CO-TANGENTS

′	0°		1°		2°		3°		′
	TAN.	CO-TAN.	TAN.	CO-TAN.	TAN.	CO-TAN.	TAN.	CO-TAN.	
0	.00000	Infinite.	.01746	57.2900	.03492	28.6363	.05241	19.0811	60
1	.00029	3437.750	.01775	56.3506	.03521	28.3994	.05270	18.9755	59
2	.00058	1718.870	.01804	55.4415	.03550	28.1664	.05299	18.8711	58
3	.00087	1145.920	.01833	54.5613	.03579	27.9372	.05328	18.7678	57
4	.00116	859.436	.01862	53.7086	.03609	27.7117	.05357	18.6656	56
5	.00145	687.549	.01891	52.8821	.03638	27.4899	.05387	18.5645	55
6	.00175	572.957	.01920	52.0807	.03667	27.2715	.05416	18.4645	54
7	.00204	491.106	.01949	51.3032	.03696	27.0566	.05445	18.3655	53
8	.00233	429.718	.01978	50.5485	.03725	26.8450	.05474	18.2677	52
9	.00262	381.971	.02007	49.8157	.03754	26.6367	.05503	18.1708	51
10	.00291	343.774	.02036	49.1039	.03783	26.4316	.05533	18.0750	50
11	.00320	312.521	.02066	48.4121	.03812	26.2296	.05562	17.9802	49
12	.00349	286.478	.02095	47.7395	.03842	26.0307	.05591	17.8863	48
13	.00378	264.441	.02124	47.0853	.03871	25.8348	.05620	17.7934	47
14	.00407	245.552	.02153	46.4489	.03900	25.6418	.05649	17.7015	46
15	.00436	229.182	.02182	45.8294	.03929	25.4517	.05678	17.6106	45
16	.00465	214.858	.02211	45.2261	.03958	25.2644	.05708	17.5205	44
17	.00495	202.219	.02240	44.6386	.03987	25.0798	.05737	17.4314	43
18	.00524	190.984	.02269	44.0661	.04016	24.8978	.05766	17.3432	42
19	.00553	180.932	.02298	43.5081	.04046	24.7185	.05795	17.2558	41
20	.00582	171.885	.02328	42.9641	.04075	24.5418	.05824	17.1693	40
21	.00611	163.700	.02357	42.4335	.04104	24.3675	.05854	17.0837	39
22	.00640	156.259	.02386	41.9158	.04133	24.1957	.05883	16.9990	38
23	.00669	149.465	.02415	41.4106	.04162	24.0263	.05912	16.9150	37
24	.00698	143.237	.02444	40.9174	.04191	23.8593	.05941	16.8319	36
25	.00727	137.507	.02473	40.4358	.04220	23.6945	.05970	16.7496	35
26	.00756	132.219	.02502	39.9655	.04250	23.5321	.05999	16.6681	34
27	.00785	127.321	.02531	39.5059	.04279	23.3718	.06029	16.5874	33
28	.00814	122.774	.02560	39.0568	.04308	23.2137	.06058	16.5075	32
29	.00844	118.540	.02589	38.6177	.04337	23.0577	.06087	16.4283	31
30	.00873	114.589	.02619	38.1885	.04366	22.9038	.06116	16.3499	30
31	.00902	110.892	.02648	37.7686	.04395	22.7519	.06145	16.2722	29
32	.00931	107.426	.02677	37.3579	.04424	22.6020	.06175	16.1952	28
33	.00960	104.171	.02706	36.9560	.04454	22.4541	.06204	16.1190	27
34	.00989	101.107	.02735	36.5627	.04483	22.3081	.06233	16.0435	26
35	.01018	98.2179	.02764	36.1776	.04512	22.1640	.06262	15.9687	25
36	.01047	95.4895	.02793	35.8006	.04541	22.0217	.06291	15.8945	24
37	.01076	92.9085	.02822	35.4313	.04570	21.8813	.06321	15.8211	23
38	.01105	90.4633	.02851	35.0695	.04599	21.7426	.06350	15.7483	22
39	.01135	88.1436	.02881	34.7151	.04628	21.6056	.06379	15.6762	21
40	.01164	85.9398	.02910	34.3678	.04658	21.4704	.06408	15.6048	20
41	.01193	83.8435	.02939	34.0273	.04687	21.3369	.06437	15.5340	19
42	.01222	81.8470	.02968	33.6935	.04716	21.2049	.06467	15.4638	18
43	.01251	79.9434	.02997	33.3662	.04745	21.0747	.06496	15.3943	17
44	.01280	78.1263	.03026	33.0452	.04774	20.9460	.06525	15.3254	16
45	.01309	76.3900	.03055	32.7303	.04803	20.8188	.06554	15.2571	15
46	.01338	74.7292	.03084	32.4213	.04832	20.6932	.06584	15.1893	14
47	.01367	73.1390	.03114	32.1181	.04862	20.5691	.06613	15.1222	13
48	.01396	71.6151	.03143	31.8205	.04891	20.4465	.06642	15.0557	12
49	.01425	70.1533	.03172	31.5284	.04920	20.3253	.06671	14.9898	11
50	.01455	68.7501	.03201	31.2416	.04949	20.2056	.06700	14.9244	10
51	.01484	67.4019	.03230	30.9599	.04978	20.0872	.06730	14.8596	9
52	.01513	66.1055	.03259	30.6833	.05007	19.9702	.06759	14.7954	8
53	.01542	64.8580	.03288	30.4116	.05037	19.8546	.06788	14.7317	7
54	.01571	63.6567	.03317	30.1446	.05066	19.7403	.06817	14.6685	6
55	.01600	62.4992	.03346	29.8823	.05095	19.6273	.06847	14.6059	5
56	.01629	61.3829	.03376	29.6245	.05124	19.5156	.06876	14.5438	4
57	.01658	60.3058	.03405	29.3711	.05153	19.4051	.06905	14.4823	3
58	.01687	59.2659	.03434	29.1220	.05182	19.2959	.06934	14.4212	2
59	.01716	58.2612	.03463	28.8771	.05212	19.1879	.06963	14.3607	1
60	.01746	57.2900	.03492	28.6363	.05241	19.0811	.06993	14.3007	0
′	CO-TAN.	TAN.	CO-TAN.	TAN.	CO-TAN.	TAN.	CO-TAN.	TAN.	′
	89°		88°		87°		86°		

	4°		5°		6°		7°		
′	Tan.	Co-tan.	Tan.	Co-tan.	Tan.	Co-tan.	Tan.	Co-tan.	′
0	.06993	14.3007	.08749	11.4301	.10510	9.51436	.12278	8.14435	6
1	.07022	14.2411	.08778	11.3919	.10540	9.48781	.12308	8.12481	5
2	.07051	14.1821	.08807	11.3540	.10569	9.46141	.12338	8.10536	5
3	.07080	14.1235	.08837	11.3163	.10599	9.43515	.12367	8.08600	5
4	.07110	14.0655	.08866	11.2789	.10628	9.40904	.12397	8.06674	5
5	.07139	14.0079	.08895	11.2417	.10657	9.38307	.12426	8.04756	5
6	.07168	13.9507	.08925	11.2048	.10687	9.35724	.12456	8.02848	5
7	.07197	13.8940	.08954	11.1681	.10716	9.33154	.12485	8.00948	5
8	.07227	13.8378	.08983	11.1316	.10746	9.30599	.12515	7.99058	5
9	.07256	13.7821	.09013	11.0954	.10775	9.28058	.12544	7.97176	5
10	.07285	13.7267	.09042	11.0594	.10805	9.25530	.12574	7.95302	5
11	.07314	13.6719	.09071	11.0237	.10834	9.23016	.12603	7.93438	4
12	.07344	13.6174	.09101	10.9882	.10863	9.20516	.12633	7.91582	4
13	.07373	13.5634	.09130	10.9529	.10893	9.18028	.12662	7.89734	4
14	.07402	13.5098	.09159	10.9178	.10922	9.15554	.12692	7.87895	4
15	.07431	13.4566	.09189	10.8829	.10952	9.13093	.12722	7.86064	4
16	.07461	13.4039	.09218	10.8483	.10981	9.10646	.12751	7.84242	4
17	.07490	13.3515	.09247	10.8139	.11011	9.08211	.12781	7.82428	4
18	.07519	13.2996	.09277	10.7797	.11040	9.05789	.12810	7.80622	4
19	.07548	13.2480	.09306	10.7457	.11070	9.03379	.12840	7.78825	4
20	.07578	13.1969	.09335	10.7119	.11099	9.00983	.12869	7.77035	4
21	.07607	13.1461	.09365	10.6783	.11128	8.98598	.12899	7.75254	3
22	.07636	13.0958	.09394	10.6450	.11158	8.96227	.12929	7.73480	3
23	.07665	13.0458	.09423	10.6118	.11187	8.93867	.12958	7.71715	3
24	.07695	12.9962	.09453	10.5789	.11217	8.91520	.12988	7.69957	3
25	.07724	12.9469	.09482	10.5462	.11246	8.89185	.13017	7.68208	3
26	.07753	12.8981	.09511	10.5136	.11276	8.86862	.13047	7.66466	3
27	.07782	12.8496	.09541	10.4813	.11305	8.84551	.13076	7.64732	3
28	.07812	12.8014	.09570	10.4491	.11335	8.82252	.13106	7.63005	3
29	.07841	12.7536	.09600	10.4172	.11364	8.79964	.13136	7.61287	3
30	.07870	12.7062	.09629	10.3854	.11394	8.77689	.13165	7.59575	3
31	.07899	12.6591	.09658	10.3538	.11423	8.75425	.13195	7.57872	2
32	.07929	12.6124	.09688	10.3224	.11452	8.73172	.13224	7.56176	2
33	.07958	12.5660	.09717	10.2913	.11482	8.70931	.13254	7.54487	2
34	.07987	12.5199	.09746	10.2602	.11511	8.68701	.13284	7.52806	2
35	.08017	12.4742	.09776	10.2294	.11541	8.66482	.13313	7.51132	2
36	.08046	12.4288	.09805	10.1988	.11570	8.64275	.13343	7.49465	2
37	.08075	12.3838	.09834	10.1683	.11600	8.62078	.13372	7.47806	2
38	.08104	12.3390	.09864	10.1381	.11629	8.59893	.13402	7.46154	2
39	.08134	12.2946	.09893	10.1080	.11659	8.57718	.13432	7.44509	2
40	.08163	12.2505	.09923	10.0780	.11688	8.55555	.13461	7.42871	2
41	.08192	12.2067	.09952	10.0483	.11718	8.53402	.13491	7.41240	1
42	.08221	12.1632	.09981	10.0187	.11747	8.51259	.13521	7.39616	1
43	.08251	12.1201	.10011	9.98931	.11777	8.49128	.13550	7.37999	1
44	.08280	12.0772	.10040	9.96007	.11806	8.47007	.13580	7.36389	1
45	.08309	12.0346	.10069	9.93101	.11836	8.44896	.13609	7.34786	1
46	.08339	11.9923	.10099	9.90211	.11865	8.42795	.13639	7.33190	1
47	.08368	11.9504	.10128	9.87338	.11895	8.40705	.13669	7.31600	1
48	.08397	11.9087	.10158	9.84482	.11924	8.38625	.13698	7.30018	1
49	.08427	11.8673	.10187	9.81641	.11954	8.36555	.13728	7.28442	1
50	.08456	11.8262	.10216	9.78817	.11983	8.34496	.13758	7.26873	1
51	.08485	11.7853	.10246	9.76009	.12013	8.32446	.13787	7.25310	9
52	.08514	11.7448	.10275	9.73217	.12042	8.30406	.13817	7.23754	8
53	.08544	11.7045	.10305	9.70441	.12072	8.28376	.13846	7.22204	7
54	.08573	11.6645	.10334	9.67680	.12101	8.26355	.13876	7.20661	6
55	.08602	11.6248	.10363	9.64935	.12131	8.24345	.13906	7.19125	5
56	.08632	11.5853	.10393	9.62205	.12160	8.22344	.13935	7.17594	4
57	.08661	11.5461	.10422	9.59490	.12190	8.20352	.13965	7.16071	3
58	.08690	11.5072	.10452	9.56791	.12219	8.18370	.13995	7.14553	2
59	.08720	11.4685	.10481	9.54106	.12249	8.16398	.14024	7.13042	1
60	.08749	11.4301	.10510	9.51436	.12278	8.14435	.14054	7.11537	0
′	Co-tan.	Tan.	Co-tan.	Tan.	Co-tan.	Tan.	Co-tan.	Tan.	′
	85°		84°		83°		82°		

′	8° Tan.	8° Co-tan.	9° Tan.	9° Co-tan.	10° Tan.	10° Co-tan.	11° Tan.	11° Co-tan.	′
0	.14054	7.11537	.15838	6.31375	.17633	5.67128	.19438	5.14455	60
1	.14084	7.10038	.15868	6.30189	.17663	5.66165	.19468	5.13658	59
2	.14113	7.08546	.15898	6.29007	.17693	5.65205	.19498	5.12862	58
3	.14143	7.07059	.15928	6.27829	.17723	5.64248	.19529	5.12069	57
4	.14173	7.05579	.15958	6.26655	.17753	5.63295	.19559	5.11279	56
5	.14202	7.04105	.15988	6.25486	.17783	5.62344	.19589	5.10490	55
6	.14232	7.02637	.16017	6.24321	.17813	5.61397	.19619	5.09704	54
7	.14262	7.01174	.16047	6.23160	.17843	5.60452	.19649	5.08921	53
8	.14291	6.99718	.16077	6.22003	.17873	5.59511	.19680	5.08139	52
9	.14321	6.98268	.16107	6.20851	.17903	5.58573	.19710	5.07360	51
10	.14351	6.96823	.16137	6.19703	.17933	5.57638	.19740	5.06584	50
11	.14381	6.95385	.16167	6.18559	.17963	5.56706	.19770	5.05809	49
12	.14410	6.93952	.16196	6.17419	.17993	5.55777	.19801	5.05037	48
13	.14440	6.92525	.16226	6.16283	.18023	5.54851	.19831	5.04267	47
14	.14470	6.91104	.16256	6.15151	.18053	5.53927	.19861	5.03499	46
15	.14499	6.89688	.16286	6.14023	.18083	5.53007	.19891	5.02734	45
16	.14529	6.88278	.16316	6.12899	.18113	5.52090	.19921	5.01971	44
17	.14559	6.86874	.16346	6.11779	.18143	5.51176	.19952	5.01210	43
18	.14588	6.85475	.16376	6.10664	.18173	5.50264	.19982	5.00451	42
19	.14618	6.84082	.16405	6.09552	.18203	5.49356	.20012	4.99695	41
20	.14648	6.82694	.16435	6.08444	.18233	5.48451	.20042	4.98940	40
21	.14678	6.81312	.16465	6.07340	.18263	5.47548	.20073	4.98188	39
22	.14707	6.79936	.16495	6.06240	.18293	5.46648	.20103	4.97438	38
23	.14737	6.78564	.16525	6.05143	.18323	5.45751	.20133	4.96690	37
24	.14767	6.77199	.16555	6.04051	.18353	5.44857	.20164	4.95945	36
25	.14796	6.75838	.16585	6.02962	.18383	5.43966	.20194	4.95201	35
26	.14826	6.74483	.16615	6.01878	.18414	5.43077	.20224	4.94460	34
27	.14856	6.73133	.16645	6.00797	.18444	5.42192	.20254	4.93721	33
28	.14886	6.71789	.16674	5.99720	.18474	5.41309	.20285	4.92984	32
29	.14915	6.70450	.16704	5.98646	.18504	5.40429	.20315	4.92249	31
30	.14945	6.69116	.16734	5.97576	.18534	5.39552	.20345	4.91516	30
31	.14975	6.67787	.16764	5.96510	.18564	5.38677	.20376	4.90785	29
32	.15005	6.66463	.16794	5.95448	.18594	5.37805	.20406	4.90056	28
33	.15034	6.65144	.16824	5.94390	.18624	5.36936	.20436	4.89330	27
34	.15064	6.63831	.16854	5.93335	.18654	5.36070	.20466	4.83605	26
35	.15094	6.62523	.16884	5.92283	.18684	5.35206	.20497	4.87882	25
36	.15124	6.61219	.16914	5.91235	.18714	5.34345	.20527	4.87162	24
37	.15153	6.59921	.16944	5.90191	.18745	5.33487	.20557	4.86444	23
38	.15183	6.58627	.16974	5.89151	.18775	5.32631	.20588	4.85727	22
39	.15213	6.57339	.17004	5.88114	.18805	5.31778	.20618	4.85013	21
40	.15243	6.56055	.17033	5.87080	.18835	5.30928	.20648	4.84300	20
41	.15272	6.54777	.17063	5.86051	.18865	5.30080	.20679	4.83590	19
42	.15302	6.53503	.17093	5.85024	.18895	5.29235	.20709	4.82882	18
43	.15332	6.52234	.17123	5.84001	.18925	5.28393	.20739	4.82175	17
44	.15362	6.50970	.17153	5.82982	.18955	5.27553	.20770	4.81471	16
45	.15391	6.49710	.17183	5.81966	.18986	5.26715	.20800	4.80769	15
46	.15421	6.48456	.17213	5.80953	.19016	5.25880	.20830	4.80068	14
47	.15451	6.47206	.17243	5.79944	.19046	5.25048	.20861	4.79370	13
48	.15481	6.45961	.17273	5.78938	.19076	5.24218	.20891	4.78673	12
49	.15511	6.44720	.17303	5.77936	.19106	5.23391	.20921	4.77978	11
50	.15540	6.43484	.17333	5.76937	.19136	5.22566	.20952	4.77286	10
51	.15570	6.42253	.17363	5.75941	.19166	5.21744	.20982	4.76595	9
52	.15600	6.41026	.17393	5.74949	.19197	5.20925	.21013	4.75906	8
53	.15630	6.39804	.17423	5.73960	.19227	5.20107	.21043	4.75219	7
54	.15660	6.38587	.17453	5.72974	.19257	5.19293	.21073	4.74534	6
55	.15689	6.37374	.17483	5.71992	.19287	5.18480	.21104	4.73851	5
56	.15719	6.36165	.17513	5.71013	.19317	5.17671	.21134	4.73170	4
57	.15749	6.34961	.17543	5.70037	.19347	5.16863	.21164	4.72490	3
58	.15779	6.33761	.17573	5.69064	.19378	5.16058	.21195	4.71813	2
59	.15809	6.32566	.17603	5.68094	.19408	5.15256	.21225	4.71137	1
60	.15838	6.31375	.17633	5.67128	.19438	5.14455	.21256	4.70463	0
	Co-tan. 81°	Tan. 81°	Co-tan. 80°	Tan. 80°	Co-tan. 79°	Tan. 79°	Co-tan. 78°	Tan. 78°	′

′	12°		13°		14°		15°	
	Tan.	Co-tan.	Tan.	Co-tan.	Tan.	Co-tan.	Tan.	Co-tan.
0	.21256	4.70463	.23087	4.33148	.24933	4.01078	.26795	3.73205
1	.21286	4.69791	.23117	4.32573	.24964	4.00582	.26826	3.72771
2	.21316	4.69121	.23148	4.32001	.24995	4.00086	.26857	3.72338
3	.21347	4.68452	.23179	4.31430	.25026	3.99592	.26888	3.71907
4	.21377	4.67786	.23209	4.30860	.25056	3.99099	.26920	3.71476
5	.21408	4.67121	.23240	4.30291	.25087	3.98607	.26951	3.71046
6	.21438	4.66458	.23271	4.29724	.25118	3.98117	.26982	3.70616
7	.21469	4.65797	.23301	4.29159	.25149	3.97627	.27013	3.70188
8	.21499	4.65138	.23332	4.28595	.25180	3.97139	.27044	3.69761
9	.21529	4.64480	.23363	4.28032	.25211	3.96651	.27076	3.69335
10	.21560	4.63825	.23393	4.27471	.25242	3.96165	.27107	3.68909
11	.21590	4.63171	.23424	4.26911	.25273	3.95680	.27138	3.68485
12	.21621	4.62518	.23455	4.26352	.25304	3.95196	.27169	3.68061
13	.21651	4.61868	.23485	4.25795	.25335	3.94713	.27201	3.67638
14	.21682	4.61219	.23516	4.25239	.25366	3.94232	.27232	3.67217
15	.21712	4.60572	.23547	4.24685	.25397	3.93751	.27263	3.66796
16	.21743	4.59927	.23578	4.24132	.25428	3.93271	.27294	3.66376
17	.21773	4.59283	.23608	4.23580	.25459	3.92793	.27326	3.65957
18	.21804	4.58641	.23639	4.23030	.25490	3.92316	.27357	3.65538
19	.21834	4.58001	.23670	4.22481	.25521	3.91839	.27388	3.65121
20	.21864	4.57363	.23700	4.21933	.25552	3.91364	.27419	3.64705
21	.21895	4.56726	.23731	4.21387	.25583	3.90890	.27451	3.64289
22	.21925	4.56091	.23762	4.20842	.25614	3.90417	.27482	3.63874
23	.21956	4.55458	.23793	4.20298	.25645	3.89945	.27513	3.63461
24	.21986	4.54826	.23823	4.19756	.25676	3.89474	.27545	3.63048
25	.22017	4.54196	.23854	4.19215	.25707	3.89004	.27576	3.62636
26	.22047	4.53568	.23885	4.18675	.25738	3.88536	.27607	3.62224
27	.22078	4.52941	.23916	4.18137	.25769	3.88068	.27638	3.61814
28	.22108	4.52316	.23946	4.17600	.25800	3.87601	.27670	3.61405
29	.22139	4.51693	.23977	4.17064	.25831	3.87136	.27701	3.60996
30	.22169	4.51071	.24008	4.16530	.25862	3.86671	.27732	3.60588
31	.22200	4.50451	.24039	4.15997	.25893	3.86208	.27764	3.60181
32	.22231	4.49832	.24069	4.15465	.25924	3.85745	.27795	3.59775
33	.22261	4.49215	.24100	4.14934	.25955	3.85284	.27826	3.59370
34	.22292	4.48600	.24131	4.14405	.25986	3.84824	.27858	3.58966
35	.22322	4.47986	.24162	4.13877	.26017	3.84364	.27889	3.58562
36	.22353	4.47374	.24193	4.13350	.26048	3.83906	.27920	3.58160
37	.22383	4.46764	.24223	4.12825	.26079	3.83449	.27952	3.57758
38	.22414	4.46155	.24254	4.12301	.26110	3.82992	.27983	3.57357
39	.22444	4.45548	.24285	4.11778	.26141	3.82537	.28015	3.56957
40	.22475	4.44942	.24316	4.11256	.26172	3.82083	.28046	3.56557
41	.22505	4.44338	.24347	4.10736	.26203	3.81630	.28077	3.56159
42	.22536	4.43735	.24377	4.10216	.26235	3.81177	.28109	3.55761
43	.22567	4.43134	.24408	4.09699	.26266	3.80726	.28140	3.55364
44	.22597	4.42534	.24439	4.09182	.26297	3.80276	.28172	3.54968
45	.22628	4.41936	.24470	4.08666	.26328	3.79827	.28203	3.54573
46	.22658	4.41340	.24501	4.08152	.26359	3.79378	.28234	3.54179
47	.22689	4.40745	.24532	4.07639	.26390	3.78931	.28266	3.53785
48	.22719	4.40152	.24562	4.07127	.26421	3.78485	.28297	3.53393
49	.22750	4.39560	.24593	4.06616	.26452	3.78040	.28329	3.53001
50	.22781	4.38969	.24624	4.06107	.26483	3.77595	.28360	3.52609
51	.22811	4.38381	.24655	4.05599	.26515	3.77152	.28391	3.52219
52	.22842	4.37793	.24686	4.05092	.26546	3.76709	.28423	3.51829
53	.22872	4.37207	.24717	4.04586	.26577	3.76268	.28454	3.51441
54	.22903	4.36623	.24747	4.04081	.26608	3.75828	.28486	3.51053
55	.22934	4.36040	.24778	4.03578	.26639	3.75388	.28517	3.50666
56	.22964	4.35459	.24809	4.03075	.26670	3.74950	.28549	3.50279
57	.22995	4.34879	.24840	4.02574	.26701	3.74512	.28580	3.49894
58	.23026	4.34300	.24871	4.02074	.26733	3.74075	.28612	3.49509
59	.23056	4.33723	.24902	4.01576	.26764	3.73640	.28643	3.49125
60	.23087	4.33148	.24933	4.01078	.26795	3.73205	.28675	3.48741
′	Co-tan.	Tan.	Co-tan.	Tan.	Co-tan.	Tan.	Co-tan.	Tan.
	77°		76°		75°		74°	

′	16° Tan.	16° Co-tan.	17° Tan.	17° Co-tan.	18° Tan.	18° Co-tan.	19° Tan.	19° Co-tan.	′
0	.28675	3.48741	.30573	3.27085	.32492	3.07768	.34433	2.90421	60
1	.28706	3.48359	.30605	3.26745	.32524	3.07464	.34465	2.90147	59
2	.28738	3.47977	.30637	3.26406	.32556	3.07160	.34498	2.89873	58
3	.28769	3.47596	.30669	3.26067	.32588	3.06857	.34530	2.89600	57
4	.28800	3.47216	.30700	3.25729	.32621	3.06554	.34563	2.89327	56
5	.28832	3.46837	.30732	3.25392	.32653	3.06252	.34596	2.89055	55
6	.28864	3.46458	.30764	3.25055	.32685	3.05950	.34628	2.88783	54
7	.28895	3.46080	.30796	3.24719	.32717	3.05649	.34661	2.88511	53
8	.28927	3.45703	.30828	3.24383	.32749	3.05349	.34693	2.88240	52
9	.28958	3.45327	.30860	3.24049	.32782	3.05049	.34726	2.87970	51
10	.28990	3.44951	.30891	3.23714	.32814	3.04749	.34758	2.87700	50
11	.29021	3.44576	.30923	3.23381	.32846	3.04450	.34791	2.87430	49
12	.29053	3.44202	.30955	3.23048	.32878	3.04152	.34824	2.87161	48
13	.29084	3.43829	.30987	3.22715	.32911	3.03854	.34856	2.86892	47
14	.29116	3.43456	.31019	3.22384	.32943	3.03556	.34889	2.86624	46
15	.29147	3.43084	.31051	3.22053	.32975	3.03260	.34922	2.86356	45
16	.29179	3.42713	.31083	3.21722	.33007	3.02963	.34954	2.86089	44
17	.29210	3.42343	.31115	3.21392	.33040	3.02667	.34987	2.85822	43
18	.29242	3.41973	.31147	3.21063	.33072	3.02372	.35019	2.85555	42
19	.29274	3.41604	.31178	3.20734	.33104	3.02077	.35052	2.85289	41
20	.29305	3.41236	.31210	3.20406	.33136	3.01783	.35085	2.85023	40
21	.29337	3.40869	.31242	3.20079	.33160	3.01489	.35117	2.84758	39
22	.29368	3.40502	.31274	3.19752	.33201	3.01196	.35150	2.84494	38
23	.29400	3.40136	.31306	3.19426	.33233	3.00903	.35183	2.84229	37
24	.29432	3.39771	.31338	3.19100	.33266	3.00611	.35216	2.83965	36
25	.29463	3.39406	.31370	3.18775	.33298	3.00319	.35248	2.83702	35
26	.29495	3.39042	.31402	3.18451	.33330	3.00028	.35281	2.83439	34
27	.29526	3.38679	.31434	3.18127	.33363	2.99738	.35314	2.83176	33
28	.29558	3.38317	.31466	3.17804	.33395	2.99447	.35346	2.82914	32
29	.29590	3.37955	.31498	3.17481	.33427	2.99158	.35379	2.82653	31
30	.29621	3.37594	.31530	3.17159	.33460	2.98868	.35412	2.82391	30
31	.29653	3.37234	.31562	3.16838	.33492	2.98580	.35445	2.82130	29
32	.29685	3.36875	.31594	3.16517	.33524	2.98292	.35477	2.81870	28
33	.29716	3.36516	.31626	3.16197	.33557	2.98004	.35510	2.81610	27
34	.29748	3.36158	.31658	3.15877	.33589	2.97717	.35543	2.81350	26
35	.29780	3.35800	.31690	3.15558	.33621	2.97430	.35576	2.81091	25
36	.29811	3.35443	.31722	3.15240	.33654	2.97144	.35608	2.80833	24
37	.29843	3.35087	.31754	3.14922	.33686	2.96858	.35641	2.80574	23
38	.29875	3.34732	.31786	3.14605	.33718	2.96573	.35674	2.80316	22
39	.29906	3.34377	.31818	3.14288	.33751	2.96288	.35707	2.80059	21
40	.29938	3.34023	.31850	3.13972	.33783	2.96004	.35740	2.79802	20
41	.29970	3.33670	.31882	3.13656	.33816	2.95721	.35772	2.79545	19
42	.30001	3.33317	.31914	3.13341	.33848	2.95437	.35805	2.79289	18
43	.30033	3.32965	.31946	3.13027	.33881	2.95155	.35838	2.79033	17
44	.30065	3.32614	.31978	3.12713	.33913	2.94872	.35871	2.78778	16
45	.30097	3.32264	.32010	3.12400	.33945	2.94590	.35904	2.78523	15
46	.30128	3.31914	.32042	3.12087	.33978	2.94309	.35937	2.78269	14
47	.30160	3.31565	.32074	3.11775	.34010	2.94028	.35969	2.78014	13
48	.30192	3.31216	.32106	3.11464	.34043	2.93748	.36002	2.77761	12
49	.30224	3.30868	.32139	3.11153	.34075	2.93468	.36035	2.77507	11
50	.30255	3.30521	.32171	3.10842	.34108	2.93189	.36068	2.77254	10
51	.30287	3.30174	.32203	3.10532	.34140	2.92910	.36101	2.77002	9
52	.30319	3.29829	.32235	3.10223	.34173	2.92632	.36134	2.76750	8
53	.30351	3.29483	.32267	3.09914	.34205	2.92354	.36167	2.76498	7
54	.30382	3.29139	.32299	3.09606	.34238	2.92076	.36199	2.76247	6
55	.30414	3.28795	.32331	3.09298	.34270	2.91799	.36232	2.75996	5
56	.30446	3.28452	.32363	3.08991	.34303	2.91523	.36265	2.75746	4
57	.30478	3.28109	.32396	3.08685	.34335	2.91246	.36298	2.75496	3
58	.30509	3.27767	.32428	3.08379	.34368	2.90971	.36331	2.75246	2
59	.30541	3.27426	.32460	3.08073	.34400	2.90696	.36364	2.74997	1
60	.30573	3.27085	.32492	3.07768	.34433	2.90421	.36397	2.74748	0
	Co-tan. 73°	Tan. 73°	Co-tan. 72°	Tan. 72°	Co-tan. 71°	Tan. 71°	Co-tan. 70°	Tan. 70°	′

′	20°		21°		22°		23°	
	Tan.	Co-tan.	Tan.	Co-tan.	Tan.	Co-tan.	Tan.	Co-tan.
0	.36397	2.74748	.38386	2.60509	.40403	2.47509	.42447	2.35585
1	.36430	2.74499	.38420	2.60283	.40436	2.47302	.42482	2.35395
2	.36463	2.74251	.38453	2.60057	.40470	2.47095	.42516	2.35205
3	.36496	2.74004	.38487	2.59831	.40504	2.46888	.42551	2.35015
4	.36529	2.73756	.38520	2.59606	.40538	2.46682	.42585	2.34825
5	.36562	2.73509	.38553	2.59381	.40572	2.46476	.42619	2.34636
6	.36595	2.73263	.38587	2.59156	.40606	2.46270	.42654	2.34447
7	.36628	2.73017	.38620	2.58932	.40640	2.46065	.42688	2.34258
8	.36661	2.72771	.38654	2.58708	.40674	2.45860	.42722	2.34069
9	.36694	2.72526	.38687	2.58484	.40707	2.45655	.42757	2.33881
10	.36727	2.72281	.38721	2.58261	.40741	2.45451	.42791	2.33693
11	.36760	2.72036	.38754	2.58038	.40775	2.45246	.42826	2.33505
12	.36793	2.71792	.38787	2.57815	.40809	2.45043	.42860	2.33317
13	.36826	2.71548	.38821	2.57593	.40843	2.44839	.42894	2.33130
14	.36859	2.71305	.38854	2.57371	.40877	2.44636	.42929	2.32943
15	.36892	2.71062	.38888	2.57150	.40911	2.44433	.42963	2.32756
16	.36925	2.70819	.38921	2.56928	.40945	2.44230	.42998	2.32570
17	.36958	2.70577	.38955	2.56707	.40979	2.44027	.43032	2.32383
18	.36991	2.70335	.38988	2.56487	.41013	2.43825	.43067	2.32197
19	.37024	2.70094	.39022	2.56266	.41047	2.43623	.43101	2.32012
20	.37057	2.69853	.39055	2.56046	.41081	2.43422	.43136	2.31826
21	.37090	2.69612	.39089	2.55827	.41115	2.43220	.43170	2.31641
22	.37124	2.69371	.39122	2.55608	.41149	2.43019	.43205	2.31456
23	.37157	2.69131	.39156	2.55389	.41183	2.42819	.43239	2.31271
24	.37190	2.68892	.39190	2.55170	.41217	2.42618	.43274	2.31086
25	.37223	2.68653	.39223	2.54952	.41251	2.42418	.43308	2.30902
26	.37256	2.68414	.39257	2.54734	.41285	2.42218	.43343	2.30718
27	.37289	2.68175	.39290	2.54516	.41319	2.42019	.43378	2.30534
28	.37322	2.67937	.39324	2.54299	.41353	2.41819	.43412	2.30351
29	.37355	2.67700	.39357	2.54082	.41387	2.41620	.43447	2.30167
30	.37388	2.67462	.39391	2.53865	.41421	2.41421	.43481	2.29984
31	.37422	2.67225	.39425	2.53648	.41455	2.41223	.43516	2.29801
32	.37455	2.66989	.39458	2.53432	.41490	2.41025	.43550	2.29619
33	.37488	2.66752	.39492	2.53217	.41524	2.40827	.43585	2.29437
34	.37521	2.66516	.39526	2.53001	.41558	2.40629	.43620	2.29254
35	.37554	2.66281	.39559	2.52786	.41592	2.40432	.43654	2.29073
36	.37588	2.66046	.39593	2.52571	.41626	2.40235	.43689	2.28891
37	.37621	2.65811	.39626	2.52357	.41660	2.40038	.43724	2.28710
38	.37654	2.65576	.39660	2.52142	.41694	2.39841	.43758	2.28528
39	.37687	2.65342	.39694	2.51929	.41728	2.39645	.43793	2.28348
40	.37720	2.65109	.39727	2.51715	.41763	2.39449	.43828	2.28167
41	.37754	2.64875	.39761	2.51502	.41797	2.39253	.43862	2.27987
42	.37787	2.64642	.39795	2.51289	.41831	2.39058	.43897	2.27806
43	.37820	2.64410	.39829	2.51076	.41865	2.38862	.43932	2.27626
44	.37853	2.64177	.39862	2.50864	.41899	2.38668	.43966	2.27447
45	.37887	2.63945	.39896	2.50652	.41933	2.38473	.44001	2.27267
46	.37920	2.63714	.39930	2.50440	.41968	2.38279	.44036	2.27088
47	.37953	2.63483	.39963	2.50229	.42002	2.38084	.44071	2.26909
48	.37986	2.63252	.39997	2.50018	.42036	2.37891	.44105	2.26730
49	.38020	2.63021	.40031	2.49807	.42070	2.37697	.44140	2.26552
50	.38053	2.62791	.40065	2.49597	.42105	2.37504	.44175	2.26374
51	.38086	2.62561	.40098	2.49386	.42139	2.37311	.44210	2.26196
52	.38120	2.62332	.40132	2.49177	.42173	2.37118	.44244	2.26018
53	.38153	2.62103	.40166	2.48967	.42207	2.36925	.44279	2.25840
54	.38186	2.61874	.40200	2.48758	.42242	2.36733	.44314	2.25663
55	.38220	2.61646	.40234	2.48549	.42276	2.36541	.44349	2.25486
56	.38253	2.61418	.40267	2.48340	.42310	2.36349	.44384	2.25309
57	.38286	2.61190	.40301	2.48132	.42345	2.36158	.44418	2.25132
58	.38320	2.60963	.40335	2.47924	.42379	2.35967	.44453	2.24956
59	.38353	2.60736	.40369	2.47716	.42413	2.35776	.44488	2.24780
60	.38386	2.60509	.40403	2.47509	.42447	2.35585	.44523	2.24604
′	Co-tan.	Tan.	Co-tan.	Tan.	Co-tan.	Tan.	Co-tan.	Tan.
	69°		68°		67°		66°	

′	24° Tan.	24° Co-tan.	25° Tan.	25° Co-tan.	26° Tan.	26° Co-tan.	27° Tan.	27° Co-tan.	
0	.44523	2.24604	.46631	2.14451	.48773	2.05030	.50953	1.96261	60
1	.44558	2.24428	.46666	2.14288	.48809	2.04879	.50989	1.96120	59
2	.44593	2.24252	.46702	2.14125	.48845	2.04728	.51026	1.95979	58
3	.44627	2.24077	.46737	2.13963	.48881	2.04577	.51063	1.95838	57
4	.44662	2.23902	.46772	2.13801	.48917	2.04426	.51099	1.95698	56
5	.44697	2.23727	.46808	2.13639	.48953	2.04276	.51136	1.95557	55
6	.44732	2.23553	.46843	2.13477	.48989	2.04125	.51173	1.95417	54
7	.44767	2.23378	.46879	2.13316	.49026	2.03975	.51209	1.95277	53
8	.44802	2.23204	.46914	2.13154	.49062	2.03825	.51246	1.95137	52
9	.44837	2.23030	.46950	2.12993	.49098	2.03675	.51283	1.94997	51
10	.44872	2.22857	.46985	2.12832	.49134	2.03526	.51319	1.94858	50
11	.44907	2.22683	.47021	2.12671	.49170	2.03376	.51356	1.94718	49
12	.44942	2.22510	.47056	2.12511	.49206	2.03227	.51393	1.94579	48
13	.44977	2.22337	.47092	2.12350	.49242	2.03078	.51430	1.94440	47
14	.45012	2.22164	.47128	2.12190	.49278	2.02929	.51467	1.94301	46
15	.45047	2.21992	.47163	2.12030	.49315	2.02780	.51503	1.94162	45
16	.45082	2.21819	.47199	2.11871	.49351	2.02631	.51540	1.94023	44
17	.45117	2.21647	.47234	2.11711	.49387	2.02483	.51577	1.93885	43
18	.45152	2.21475	.47270	2.11552	.49423	2.02335	.51614	1.93746	42
19	.45187	2.21304	.47305	2.11392	.49459	2.02187	.51651	1.93608	41
20	.45222	2.21132	.47341	2.11233	.49495	2.02039	.51688	1.93470	40
21	.45257	2.20961	.47377	2.11075	.49532	2.01891	.51724	1.93332	39
22	.45292	2.20790	.47412	2.10916	.49568	2.01743	.51761	1.93195	38
23	.45327	2.20619	.47448	2.10758	.49604	2.01596	.51798	1.93057	37
24	.45362	2.20449	.47483	2.10600	.49640	2.01449	.51835	1.92920	36
25	.45397	2.20278	.47519	2.10442	.49677	2.01302	.51872	1.92782	35
26	.45432	2.20108	.47555	2.10284	.49713	2.01155	.51909	1.92645	34
27	.45467	2.19938	.47590	2.10126	.49749	2.01008	.51946	1.92508	33
28	.45502	2.19769	.47626	2.09969	.49786	2.00862	.51983	1.92371	32
29	.45537	2.19599	.47662	2.09811	.49822	2.00715	.52020	1.92235	31
30	.45573	2.19430	.47698	2.09654	.49858	2.00569	.52057	1.92098	30
31	.45608	2.19261	.47733	2.09498	.49894	2.00423	.52094	1.91962	29
32	.45643	2.19092	.47769	2.09341	.49931	2.00277	.52131	1.91826	28
33	.45678	2.18923	.47805	2.09184	.49967	2.00131	.52168	1.91690	27
34	.45713	2.18755	.47840	2.09028	.50004	1.99986	.52205	1.91554	26
35	.45748	2.18587	.47876	2.08872	.50040	1.99841	.52242	1.91418	25
36	.45784	2.18419	.47912	2.08716	.50076	1.99695	.52279	1.91282	24
37	.45819	2.18251	.47948	2.08560	.50113	1.99550	.52316	1.91147	23
38	.45854	2.18084	.47984	2.08405	.50149	1.99406	.52353	1.91012	22
39	.45889	2.17916	.48019	2.08250	.50185	1.99261	.52390	1.90876	21
40	.45924	2.17749	.48055	2.08094	.50222	1.99116	.52427	1.90741	20
41	.45960	2.17582	.48091	2.07939	.50258	1.98972	.52464	1.90607	19
42	.45995	2.17416	.48127	2.07785	.50295	1.98828	.52501	1.90472	18
43	.46030	2.17249	.48163	2.07630	.50331	1.98684	.52538	1.90337	17
44	.46065	2.17083	.48198	2.07476	.50368	1.98540	.52575	1.90203	16
45	.46101	2.16917	.48234	2.07321	.50404	1.98396	.52613	1.90069	15
46	.46136	2.16751	.48270	2.07167	.50441	1.98253	.52650	1.89935	14
47	.46171	2.16585	.48306	2.07014	.50477	1.98110	.52687	1.89801	13
48	.46206	2.16420	.48342	2.06860	.50514	1.97966	.52724	1.89667	12
49	.46242	2.16255	.48378	2.06706	.50550	1.97823	.52761	1.89533	11
50	.46277	2.16090	.48414	2.06553	.50587	1.97680	.52798	1.89400	10
51	.46312	2.15925	.48450	2.06400	.50623	1.97538	.52836	1.89266	9
52	.46348	2.15760	.48486	2.06247	.50660	1.97395	.52873	1.89133	8
53	.46383	2.15596	.48521	2.06094	.50696	1.97253	.52910	1.89000	7
54	.46418	2.15432	.48557	2.05942	.50733	1.97111	.52947	1.88867	6
55	.46454	2.15268	.48593	2.05790	.50769	1.96969	.52984	1.88734	5
56	.46489	2.15104	.48629	2.05637	.50806	1.96827	.53022	1.88602	4
57	.46525	2.14940	.48665	2.05485	.50843	1.96685	.53059	1.88469	3
58	.46560	2.14777	.48701	2.05333	.50879	1.96544	.53096	1.88337	2
59	.46595	2.14614	.48737	2.05182	.50916	1.96402	.53134	1.88205	1
60	.46631	2.14451	.48773	2.05030	.50953	1.96261	.53171	1.88073	0
	Co-tan.	Tan.	Co-tan.	Tan.	Co-tan.	Tan.	Co-tan.	Tan.	′
	65°		64°		63°		62°		

	28°		29°		30°		31°	
	Tan.	Co-tan.	Tan.	Co-tan.	Tan.	Co-tan.	Tan.	Co-tan.
0	.53171	1.88073	.55431	1.80405	.57735	1.73205	.60086	1.66428
1	.53208	1.87941	.55469	1.80281	.57774	1.73089	.60126	1.66318
2	.53246	1.87809	.55507	1.80158	.57813	1.72973	.60165	1. 6209
3	.53283	1.87677	.55545	1.80034	.57851	1.72857	.60205	1.66099
4	.53320	1.87546	.55583	1.79911	.57890	1.72741	.60245	1.65990
5	.53358	1.87415	.55621	1.79788	.57929	1.72625	.60284	1.65881
6	.53395	1.87283	.55659	1.79665	.57968	1.72509	.60324	1.65772
7	.53432	1.87152	.55697	1.79542	.58007	1.72393	.60364	1.65663
8	.53470	1.87021	.55736	1.79419	.58046	1.72278	.60403	1.65534
9	.53507	1.86891	.55774	1.79296	.58085	1.72163	.60443	1.65445
10	.53545	1.86760	.55812	1.79174	.58124	1.72047	.60483	1.65337
11	.53582	1.86630	.55850	1.79051	.58162	1.71932	.60522	1.65228
12	.53620	1.86499	.55888	1.78929	.58201	1.71817	.60562	1.65120
13	.53657	1.86369	.55926	1.78807	.58240	1.71702	.60602	1.65011
14	.53694	1.86239	.55964	1.78685	.58279	1.71588	.60642	1.64903
15	.53732	1.86109	.56003	1.78563	.58318	1.71473	.60681	1.64795
16	.53769	1.85979	.56041	1.78441	.58357	1.71358	.60721	1.64687
17	.53807	1.85850	.56079	1.78319	.58396	1.71244	.60761	1.64579
18	.53844	1.85720	.56117	1.78198	.58435	1.71129	.60801	1.64471
19	.53882	1.85591	.56156	1.78077	.58474	1.71015	.60841	1.64363
20	.53920	1.85462	.56194	1.77955	.58513	1.70901	.60881	1.64256
21	.53957	1.85333	.56232	1.77834	.58552	1.70787	.60921	1.64148
22	.53995	1.85204	.56270	1.77713	.58591	1.70673	.60960	1.64041
23	.54032	1.85075	.56309	1.77592	.58631	1.70560	.61000	1.63934
24	.54070	1.84946	.56347	1.77471	.58670	1.70446	.61040	1.63826
25	.54107	1.84818	.56385	1.77351	.58709	1.70332	.61080	1.63719
26	.54145	1.84689	.56424	1.77230	.58748	1.70219	.61120	1.63612
27	.54183	1.84561	.56462	1.77110	.58787	1.70106	.61160	1.63505
28	.54220	1.84433	.56500	1.76990	.58826	1.69992	.61200	1.63398
29	.54258	1.84305	.56539	1.76869	.58865	1.69879	.61240	1.63292
30	.54296	1.84177	.56577	1.76749	.58904	1.69766	.61280	1.63185
31	.54333	1.84049	.56616	1.76630	.58944	1.69653	.61320	1.63079
32	.54371	1.83922	.56654	1.76510	.58983	1.69541	.61360	1.62972
33	.54409	1.83794	.56693	1.76390	.59022	1.69428	.61400	1.62866
34	.54446	1.83667	.56731	1.76271	.59061	1.69316	.61440	1.62760
35	.54484	1.83540	.56769	1.76151	.59101	1.69203	.61480	1.62654
36	.54522	1.83413	.56808	1·76032	.59140	1.69091	.61520	1.62548
37	.54560	1.83286	.56846	1.75913	.59179	1.68979	.61561	1.62442
38	.54597	1.83159	.56885	1.75794	.59218	1.68866	.61601	1.62336
39	.54635	1.83033	.56923	1.75675	.59258	1.68754	.61641	1.62230
40	.54673	1.82906	.56962	1.75556	.59297	1.68643	.61681	1.62125
41	.54711	1.82780	.57000	1.75437	.59336	1.68531	.61721	1.62019
42	.54748	1.82654	.57039	1.75319	.59376	1.68419	.61761	1.61914
43	.54786	1.82528	.57078	1.75200	.59415	1.68308	.61801	1.61808
44	.54824	1.82402	.57116	1.75082	.59454	1.68196	.61842	1.61703
45	.54862	1.82276	.57155	1.74964	.59494	1.68085	.61882	1.61598
46	.54900	1.82150	.57193	1.74846	.59533	1.67974	.61922	1.61493
47	.54938	1.82025	.57232	1.74728	.59573	1.67863	.61962	1.61388
48	.54975	1.81899	.57271	1.74610	.59612	1.67752	.62003	1.61283
49	.55013	1.81774	.57309	1.74492	.59651	1.67641	.62043	1.61179
50	.55051	1.81649	.57348	1.74375	.59691	1.67530	.62083	1.61074
51	.55089	1.81524	.57386	1.74257	.59730	1.67419	.62124	1.60970
52	.55127	1.81399	.57425	1.74140	.59770	1.67309	.62164	1.60865
53	.55165	1.81274	.57464	1.74022	.59809	1.67198	.62204	1.60761
54	.55203	1.81150	.57503	1.73905	.59849	1.67088	.62245	1.60657
55	.55241	1.81025	.57541	1.73788	.59888	1.66978	.62285	1.60553
56	.55279	1.80901	.57580	1.73671	.59928	1.66867	.62325	1.60449
57	.55317	1.80777	.57619	1.73555	.59967	1.66757	.62366	1.60345
58	.55355	1.80653	.57657	1.73438	.60007	1.66647	.62406	1.60241
59	.55393	1.80529	.57696	1.73321	.60046	1.66538	.62446	1.60137
60	.55431	1.80405	.57735	1.73205	.60086	1.66428	.62487	1.60033
	Co-tan.	Tan.	Co-tan.	Tan.	Co-tan.	Tan.	Co-tan.	Tan.
	61°		60°		59°		58°	

32°		33°		34°		35°		
Tan.	Co-tan.	Tan.	Co-tan.	Tan.	Co-tan.	Tan.	Co-tan.	′
.62487	1.60033	.64941	1.53986	.67451	1.48256	.70021	1.42815	60
.62527	1.59930	.64982	1.53888	.67493	1.48163	.70064	1.42726	59
.62568	1.59826	.65023	1.53791	.67536	1.48070	.70107	1.42638	58
.62608	1.59723	.65065	1.53693	.67578	1.47977	.70151	1.42550	57
.62649	1.59620	.65106	1.53595	.67620	1.47885	.70194	1.42462	56
.62689	1.59517	.65148	1.53497	.67663	1.47792	.70238	1.42374	55
.62730	1.59414	.65189	1.53400	.67705	1.47699	.70281	1.42286	54
.62770	1.59311	.65231	1.53302	.67748	1.47607	.70325	1.42198	53
.62811	1.59208	.65272	1.53205	.67790	1.47514	.70368	1.42110	52
.62852	1.59105	.65314	1.53107	.67832	1.47422	.70412	1.42022	51
.62892	1.59002	.65355	1.53010	.67875	1.47330	.70455	1.41934	50
.62933	1.58900	.65397	1.52913	.67917	1.47238	.70499	1.41847	49
.62973	1.58797	.65438	1.52816	.67960	1.47146	.70542	1.41759	48
.63014	1.58695	.65480	1.52719	.68002	1.47053	.70586	1.41672	47
.63055	1.58593	.65521	1.52622	.68045	1.46962	.70629	1.41584	46
.63095	1.58490	.65563	1.52525	.68088	1.46870	.70673	1.41497	45
.63136	1.58388	.65604	1.52429	.68130	1.46778	.70717	1.41409	44
.63177	1.58286	.65646	1.52332	.68173	1.46686	.70760	1.41322	43
.63217	1.58184	.65688	1.52235	.68215	1.46595	.70804	1.41235	42
.63258	1.58083	.65729	1.52139	.68258	1.46503	.70848	1.41148	41
.63299	1.57981	.65771	1.52043	.68301	1.46411	.70891	1.41061	40
.63340	1.57879	.65813	1.51946	.68343	1.46320	.70935	1.40974	39
.63380	1.57778	.65854	1.51850	.68386	1.46229	.70979	1.40887	38
.63421	1.57676	.65896	1.51754	.68429	1.46137	.71023	1.40800	37
.63462	1.57575	.65938	1.51658	.68471	1.46046	.71066	1.40714	36
.63503	1.57474	.65980	1.51562	.68514	1.45955	.71110	1.40627	35
.63544	1.57372	.66021	1.51466	.68557	1.45864	.71154	1.40540	34
.63584	1.57271	.66063	1.51370	.68600	1.45773	.71198	1.40454	33
.63625	1.57170	.66105	1.51275	.68642	1.45682	.71242	1.40367	32
.63666	1.57069	.66147	1.51179	.68685	1.45592	.71285	1.40281	31
.63707	1.56969	.66189	1.51084	.68728	1.45501	.71329	1.40195	30
.63748	1.56868	.66230	1.50988	.68771	1.45410	.71373	1.40109	29
.63789	1.56767	.66272	1.50893	.68814	1.45320	.71417	1.40022	28
.63830	1.56667	.66314	1.50797	.68857	1.45229	.71461	1.39936	27
.63871	1.56566	.66356	1.50702	.68900	1.45139	.71505	1.39850	26
.63912	1.56466	.66398	1.50607	.68942	1.45049	.71549	1.39764	25
.63953	1.56366	.66440	1.50512	.68985	1.44958	.71593	1.39679	24
.63994	1.56265	.66482	1.50417	.69028	1.44868	.71637	1.39593	23
.64035	1.56165	.66524	1.50322	.69071	1.44778	.71681	1.39507	22
.64076	1.56065	.66566	1.50228	.69114	1.44688	.71725	1.39421	21
.64117	1.55966	.66608	1.50133	.69157	1.44598	.71769	1.39336	20
.64158	1.55866	.66650	1.50038	.69200	1.44508	.71813	1.39250	19
.64199	1.55766	.66692	1.49944	.69243	1.44418	.71857	1.39165	18
.64240	1.55666	.66734	1.49849	.69286	1.44329	.71901	1.39079	17
.64281	1.55567	.66776	1.49755	.69329	1.44239	.71946	1.38994	16
.64322	1.55467	.66818	1.49661	.69372	1.44149	.71990	1.38909	15
.64363	1.55368	.66860	1.49566	.69416	1.44060	.72034	1.38824	14
.64404	1.55269	.66902	1.49472	.69459	1.43970	.72078	1.38738	13
.64446	1.55170	.66944	1.49378	.69502	1.43881	.72122	1.38653	12
.64487	1.55071	.66986	1.49284	.69545	1.43792	.72166	1.38568	11
.64528	1.54972	.67028	1.49190	.69588	1.43703	.72211	1.38484	10
.64569	1.54873	.67071	1.49097	.69631	1.43614	.72255	1.38399	9
.64610	1.54774	.67113	1.49003	.69675	1.43525	.72299	1.38314	8
.64652	1.54675	.67155	1.48909	.69718	1.43436	.72344	1.38229	7
.64693	1.54576	.67197	1.48816	.69761	1.43347	.72388	1.38145	6
.64734	1.54478	.67239	1.48722	.69804	1.43258	.72432	1.38060	5
.64775	1.54379	.67282	1.48629	.69847	1.43169	.72477	1.37976	4
.64817	1.54281	.67324	1.48536	.69891	1.43080	.72521	1.37891	3
.64858	1.54183	.67366	1.48442	.69934	1.42992	.72565	1.37807	2
.64899	1.54085	.67409	1.48349	.69977	1.42903	.72610	1.37722	1
.64941	1.53986	.67451	1.48256	.70021	1.42815	.72654	1.37638	0
Co-tan.	Tan.	Co-tan.	Tan.	Co-tan.	Tan.	Co-tan.	Tan.	′
57°		56°		55°		54°		

′	36° Tan.	36° Co-tan.	37° Tan.	37° Co-tan.	38° Tan.	38° Co-tan.	39° Tan.	39° Co-tan.
0	.72654	1.37638	.75355	1.32704	.78129	1.27994	.80978	1.23490
1	.72699	1.37554	.75401	1.32624	.78175	1.27917	.81027	1.23416
2	.72743	1.37470	.75447	1.32544	.78222	1.27841	.81075	1.23343
3	.72788	1.37386	.75492	1.32464	.78269	1.27764	.81123	1.23270
4	.72832	1.37302	.75538	1.32384	.78316	1.27688	.81171	1.23196
5	.72877	1.37218	.75584	1.32304	.78363	1.27611	.81220	1.23123
6	.72921	1.37134	.75629	1.32224	.78410	1.27535	.81268	1.23050
7	.72966	1.37050	.75675	1.32144	.78457	1.27458	.81316	1.22977
8	.73010	1.36967	.75721	1.32064	.78504	1.27382	.81364	1.22904
9	.73055	1.36883	.75767	1.31984	.78551	1.27306	.81413	1.22831
10	.73100	1.36800	.75812	1.31904	.78598	1.27230	.81461	1.22758
11	.73144	1.36716	.75858	1.31825	.78645	1.27153	.81510	1.22685
12	.73189	1.36633	.75904	1.31745	.78692	1.27077	.81558	1.22612
13	.73234	1.36549	.75950	1.31666	.78739	1.27001	.81606	1.22539
14	.73278	1.36466	.75996	1.31586	.78786	1.26925	.81655	1.22467
15	.73323	1.36383	.76042	1.31507	.78834	1.26849	.81703	1.22394
16	.73368	1.36300	.76088	1.31427	.78881	1.26774	.81752	1.22321
17	.73413	1.36217	.76134	1.31348	.78928	1.26698	.81800	1.22249
18	.73457	1.36133	.76180	1.31269	.78975	1.26622	.81849	1.22176
19	.73502	1.36051	.76226	1.31190	.79022	1.26546	.81898	1.22104
20	.73547	1.35968	.76272	1.31110	.79070	1.26471	.81946	1.22031
21	.73592	1.35885	.76318	1.31031	.79117	1.26395	.81995	1.21959
22	.73637	1.35802	.76364	1.30952	.79164	1.26319	.82044	1.21886
23	.73681	1.35719	.76410	1.30873	.79212	1.26244	.82092	1.21814
24	.73726	1.35637	.76456	1.30795	.79259	1.26169	.82141	1.21742
25	.73771	1.35554	.76502	1.30716	.79306	1.26093	.82190	1.21670
26	.73816	1.35472	.76548	1.30637	.79354	1.26018	.82238	1.21598
27	.73861	1.35389	.76594	1.30558	.79401	1.25943	.82287	1.21526
28	.73906	1.35307	.76640	1.30480	.79449	1.25867	.82336	1.21454
29	.73951	1.35224	.76686	1.30401	.79496	1.25792	.82385	1.21382
30	.73996	1.35142	.76733	1.30323	.79544	1.25717	.82434	1.21310
31	.74041	1.35060	.76779	1.30244	.79591	1.25642	.82483	1.21238
32	.74086	1.34978	.76825	1.30166	.79639	1.25567	.82531	1.21166
33	.74131	1.34896	.76871	1.30087	.79686	1.25492	.82580	1.21094
34	.74176	1.34814	.76918	1.30009	.79734	1.25417	.82629	1.21023
35	.74221	1.34732	.76964	1.29931	.79781	1.25343	.82678	1.20951
36	.74267	1.34650	.77010	1.29853	.79829	1.25268	.82727	1.20879
37	.74312	1.34568	.77057	1.29775	.79877	1.25193	.82776	1.20808
38	.74357	1.34487	.77103	1.29696	.79924	1.25118	.82825	1.20736
39	.74402	1.34405	.77149	1.29618	.79972	1.25044	.82874	1.20665
40	.74447	1.34323	.77196	1.29541	.80020	1.24969	.82923	1.20593
41	.74492	1.34242	.77242	1.29463	.80067	1.24895	.82972	1.20522
42	.74538	1.34160	.77289	1.29385	.80115	1.24820	.83022	1.20451
43	.74583	1.34079	.77335	1.29307	.80163	1.24746	.83071	1.20379
44	.74628	1.33998	.77382	1.29229	.80211	1.24672	.83120	1.20308
45	.74674	1.33916	.77428	1.29152	.80258	1.24597	.83169	1.20237
46	.74719	1.33835	.77475	1.29074	.80306	1.24523	.83218	1.20166
47	.74764	1.33754	.77521	1.28997	.80354	1.24449	.83268	1.20095
48	.74810	1.33673	.77568	1.28919	.80402	1.24375	.83317	1.20024
49	.74855	1.33592	.77615	1.28842	.80450	1.24301	.83366	1.19953
50	.74900	1.33511	.77661	1.28764	.80498	1.24227	.83415	1.19882
51	.74946	1.33430	.77708	1.28687	.80546	1.24153	.83465	1.19811
52	.74991	1.33349	.77754	1.28610	.80594	1.24079	.83514	1.19740
53	.75037	1.33268	.77801	1.28533	.80642	1.24005	.83564	1.19669
54	.75082	1.33187	.77848	1.28456	.80690	1.23931	.83613	1.19599
55	.75128	1.33107	.77895	1.28379	.80738	1.23858	.83662	1.19528
56	.75173	1.33026	.77941	1.28302	.80786	1.23784	.83712	1.19457
57	.75219	1.32946	.77988	1.28225	.80834	1.23710	.83761	1.19387
58	.75264	1.32865	.78035	1.28148	.80882	1.23637	.83811	1.19316
59	.75310	1.32785	.78082	1.28071	.80930	1.23563	.83860	1.19246
60	.75355	1.32704	.78129	1.27994	.80978	1.23490	.83910	1.19175
′	Co-tan.	Tan.	Co-tan.	Tan.	Co-tan.	Tan.	Co-tan.	Tan
	53°		52°		51°		50°	

40°		41°		42°		43°		
TAN.	CO-TAN.	TAN.	CO-TAN.	TAN.	CO-TAN.	TAN.	CO-TAN.	′
.83910	1.19175	.86929	1.15037	.90040	1.11061	.93252	1.07237	60
.83960	1.19105	.86980	1.14969	.90093	1.10996	.93306	1.07174	59
.84009	1.19035	.87031	1.14902	.90146	1.10931	.93360	1.07112	58
.84059	1.18964	.87082	1.14834	.90199	1.10867	.93415	1.07049	57
.84108	1.18894	.87133	1.14767	.90251	1.10802	.93469	1.06987	56
.84158	1.18824	.87184	1.14699	.90304	1.10737	.93524	1.06925	55
.84208	1.18754	.87236	1.14632	.90357	1.10672	.93578	1.06862	54
.84258	1.18684	.87287	1.14565	.90410	1.10607	.93633	1.06800	53
.84307	1.18614	.87338	1.14498	.90463	1.10543	.93688	1.06738	52
.84357	1.18544	.87389	1.14430	.90516	1.10478	.93742	1.06676	51
.84407	1.18474	.87441	1.14363	.90569	1.10414	.93797	1.06613	50
.84457	1.18404	.87492	1.14296	.90621	1.10349	.93852	1.06551	49
.84507	1.18334	.87543	1.14229	.90674	1.10285	.93906	1.06489	48
.84556	1.18264	.87595	1.14162	.90727	1.10220	.93961	1.06427	47
.84606	1.18194	.87646	1.14095	.90781	1.10156	.94016	1.06365	46
.84656	1.18125	.87698	1.14028	.90834	1.10091	.94071	1.06303	45
.84706	1.18055	.87749	1.13961	.90887	1.10027	.94125	1.06241	44
.84756	1.17986	.87801	1.13894	.90940	1.09963	.94180	1.06179	43
.84806	1.17916	.87852	1.13828	.90993	1.09899	.94235	1.06117	42
.84856	1.17846	.87904	1.13761	.91046	1.09834	.94290	1.06056	41
.84906	1.17777	.87955	1.13694	.91099	1.09770	.94345	1.05994	40
.84956	1.17708	.88007	1.13627	.91153	1.09706	.94400	1.05932	39
.85006	1.17638	.88059	1.13561	.91206	1.09642	.94455	1.05870	38
.85057	1.17569	.88110	1.13494	.91259	1.09578	.94510	1.05809	37
.85107	1.17500	.88162	1.13428	.91313	1.09514	.94565	1.05747	36
.85157	1.17430	.88214	1.13361	.91366	1.09450	.94620	1.05685	35
.85207	1.17361	.88265	1.13295	.91419	1.09386	.94676	1.05624	34
.85257	1.17292	.88317	1.13228	.91473	1.09322	.94731	1.05562	33
.85307	1.17223	.88369	1.13162	.91526	1.09258	.94786	1.05501	32
.85358	1.17154	.88421	1.13096	.91580	1.09195	.94841	1.05439	31
.85408	1.17085	.88473	1.13029	.91633	1.09131	.94896	1.05378	30
.85458	1.17016	.88524	1.12963	.91687	1.09067	.94952	1.05317	29
.85509	1.16947	.88576	1.12897	.91740	1.09003	.95007	1.05255	28
.85559	1.16878	.88628	1.12831	.91794	1.08940	.95062	1.05194	27
.85609	1.16809	.88680	1.12765	.91847	1.08876	.95118	1.05133	26
.85660	1.16741	.88732	1.12699	.91901	1.08813	.95173	1.05072	25
.85710	1.16672	.88784	1.12633	.91955	1.08749	.95229	1.05010	24
.85761	1.16603	.88836	1.12567	.92008	1.08686	.95284	1.04949	23
.85811	1.16535	.88888	1.12501	.92062	1.08622	.95340	1.04888	22
.85862	1.16466	.88940	1.12435	.92116	1.08559	.95395	1.04827	21
.85912	1.16398	.88992	1.12369	.92170	1.08496	.95451	1.04766	20
.85963	1.16329	.89045	1.12303	.92224	1.08432	.95506	1.04705	19
.86014	1.16261	.89097	1.12238	.92277	1.08369	.95562	1.04644	18
.86064	1.16192	.89149	1.12172	.92331	1.08306	.95618	1.04583	17
.86115	1.16124	.89201	1.12106	.92385	1.08243	.95673	1.04522	16
.86166	1.16056	.89253	1.12041	.92439	1.08179	.95729	1.04461	15
.86216	1.15987	.89306	1.11975	.92493	1.08116	.95785	1.04401	14
.86267	1.15919	.89358	1.11909	.92547	1.08053	.95841	1.04340	13
.86318	1.15851	.89410	1.11844	.92601	1.07990	.95897	1.04279	12
.86368	1.15783	.89463	1.11778	.92655	1.07927	.95952	1.04218	11
.86419	1.15715	.89515	1.11713	.92709	1.07864	.96008	1.04158	10
.86470	1.15647	.89567	1.11648	.92763	1.07801	.96064	1.04097	9
.86521	1.15579	.89620	1.11582	.92817	1.07738	.96120	1.04036	8
.86572	1.15511	.89672	1.11517	.92872	1.07676	.96176	1.03976	7
.86623	1.15443	.89725	1.11452	.92926	1.07613	.96232	1.03915	6
.86674	1.15375	.89777	1.11387	.92980	1.07550	.96288	1.03855	5
.86725	1.15308	.89830	1.11321	.93034	1.07487	.96344	1.03794	4
.86776	1.15240	.89883	1.11256	.93088	1.07425	.96400	1.03734	3
.86827	1.15172	.89935	1.11191	.93143	1.07362	.96457	1.03674	2
.86878	1.15104	.89988	1.11126	.93197	1.07299	.96513	1.03613	1
.86929	1.15037	.90040	1.11061	.93252	1.07237	.96569	1.03553	0
CO-TAN.	TAN.	CO-TAN.	TAN.	CO-TAN.	TAN.	CO-TAN.	TAN.	′
49°		48°		47°		46°		

′	44° Tan.	44° Co-tan.	′	′	44° Tan.	44° Co-tan.	′	′	44° Tan.	44° Co-tan.
0	.96569	1.03553	60	21	.97756	1.02295	39	41	.98901	1.01112
1	.96625	1.03493	59	22	.97813	1.02236	38	42	.98958	1.01053
2	.96681	1.03433	58	23	.97870	1.02176	37	43	.99016	1.00994
3	.96738	1.03372	57	24	.97927	1.02117	36	44	.99073	1.00935
4	.96794	1.03312	56	25	.97984	1.02057	35	45	.99131	1.00876
5	.96850	1.03252	55	26	.98041	1.01998	34	46	.99189	1.00818
6	.96907	1.03192	54	27	.98098	1.01939	33	47	.99247	1.00759
7	.96963	1.03132	53	28	.98155	1.01879	32	48	.99304	1.00701
8	.97020	1.03072	52	29	.98213	1.01820	31	49	.99362	1.00642
9	.97076	1.03012	51	30	.98270	1.01761	30	50	.99420	1.00583
10	.97133	1.02952	50	31	.98327	1.01702	29	51	.99478	1.00525
11	.97189	1.02892	49	32	.98384	1.01642	28	52	.99536	1.00467
12	.97246	1.02832	48	33	.98441	1.01583	27	53	.99594	1.00408
13	.97302	1.02772	47	34	.98499	1.01524	26	54	.99652	1.00350
14	.97359	1.02713	46	35	.98556	1.01465	25	55	.99710	1.00291
15	.97416	1.02653	45	36	.98613	1.01406	24	56	.99768	1.00233
16	.97472	1.02593	44	37	.98671	1.01347	23	57	.99826	1.00175
17	.97529	1.02533	43	38	.98728	1.01288	22	58	.99884	1.00116
18	.97586	1.02474	42	39	.98786	1.01229	21	59	.99942	1.00058
19	.97643	1.02414	41	40	.98843	1.01170	20	60	1	1
20	.97700	1.02355	40							
′	Co-tan. 45°	Tan. 45°	′	′	Co-tan. 45°	Tan. 45°	′	′	Co-tan. 45°	Tan. 45°

NATURAL SINES AND COSINES

′	0° Sine	0° Cosine	′	′	0° Sine	0° Cosine	′	′	0° Sine	0° Cosine
0	.00000	1	60	21	.00611	.99998	39	41	.01193	.99993
1	.00029	1	59	22	.00640	.99998	38	42	.01222	.99993
2	.00058	1	58	23	.00669	.99998	37	43	.01251	.99992
3	.00087	1	57	24	.00698	.99998	36	44	.01280	.99992
4	.00116	1	56	25	.00727	.99997	35	45	.01309	.99991
5	.00145	1	55	26	.00756	.99997	34	46	.01338	.99991
6	.00175	1	54	27	.00785	.99997	33	47	.01367	.99991
7	.00204	1	53	28	.00814	.99997	32	48	.01396	.99990
8	.00233	1	52	29	.00844	.99996	31	49	.01425	.99990
9	.00262	1	51	30	.00873	.99996	30	50	.01454	.99989
10	.00291	1	50	31	.00902	.99996	29	51	.01483	.99989
11	.00320	.99999	49	32	.00931	.99996	28	52	.01513	.99989
12	.00349	.99999	48	33	.00960	.99995	27	53	.01542	.99988
13	.00378	.99999	47	34	.00989	.99995	26	54	.01571	.99988
14	.00407	.99999	46	35	.01018	.99995	25	55	.01600	.99987
15	.00436	.99999	45	36	.01047	.99995	24	56	.01629	.99987
16	.00465	.99999	44	37	.01076	.99994	23	57	.01658	.99986
17	.00495	.99999	43	38	.01105	.99994	22	58	.01687	.99986
18	.00524	.99999	42	39	.01134	.99994	21	59	.01716	.99985
19	.00553	.99998	41	40	.01164	.99993	20	60	.01745	.99985
20	.00582	.99998	40							
′	Cosine 89°	Sine 89°	′	′	Cosine 89°	Sine 89°	′	′	Cosine 89°	Sine 89°

1°		2°		3°		4°		
Sine	Cosine	Sine	Cosine	Sine	Cosine	Sine	Cosine	′
.01745	.99985	.03490	.99939	.05234	.99863	.06976	.99756	60
.01774	.99984	.03519	.99938	.05263	.99861	.07005	.99754	59
.01803	.99984	.03548	.99937	.05292	.99860	.07034	.99752	58
.01832	.99983	.03577	.99936	.05321	.99858	.07063	.99750	57
.01862	.99983	.03606	.99935	.05350	.99857	.07092	.99748	56
.01891	.99982	.03635	.99934	.05379	.99855	.07121	.99746	55
.01920	.99982	.03664	.99933	.05408	.99854	.07150	.99744	54
.01949	.99981	.03693	.99932	.05437	.99852	.07179	.99742	53
.01978	.99980	.03723	.99931	.05466	.99851	.07208	.99740	52
.02007	.99980	.03752	.99930	.05495	.99849	.07237	.99738	51
.02036	.99979	.03781	.99929	.05524	.99847	.07266	.99736	50
.02065	.99979	.03810	.99927	.05553	.99846	.07295	.99734	49
.02094	.99978	.03839	.99926	.05582	.99844	.07324	.99731	48
.02123	.99977	.03868	.99925	.05611	.99842	.07353	.99729	47
.02152	.99977	.03897	.99924	.05640	.99841	.07382	.99727	46
.02181	.99976	.03926	.99923	.05669	.99839	.07411	.99725	45
.02211	.99976	.03955	.99922	.05698	.99838	.07440	.99723	44
.02240	.99975	.03984	.99921	.05727	.99836	.07469	.99721	43
.02269	.99974	.04013	.99919	.05756	.99834	.07498	.99719	42
.02298	.99974	.04042	.99918	.05785	.99833	.07527	.99716	41
.02327	.99973	.04071	.99917	.05814	.99831	.07556	.99714	40
.02356	.99972	.04100	.99916	.05844	.99829	.07585	.99712	39
.02385	.99972	.04129	.99915	.05873	.99827	.07614	.99710	38
.02414	.99971	.04159	.99913	.05902	.99826	.07643	.99708	37
.02443	.99970	.04188	.99912	.05931	.99824	.07672	.99705	36
.02472	.99969	.04217	.99911	.05960	.99822	.07701	.99703	35
.02501	.99969	.04246	.99910	.05989	.99821	.07730	.99701	34
.02530	.99968	.04275	.99909	.06018	.99819	.07759	.99699	33
.02560	.99967	.04304	.99907	.06047	.99817	.07788	.99696	32
.02589	.99966	.04333	.99906	.06076	.99815	.07817	.99694	31
.02618	.99966	.04362	.99905	.06105	.99813	.07846	.99692	30
.02647	.99965	.04391	.99904	.06134	.99812	.07875	.99689	29
.02676	.99964	.04420	.99902	.06163	.99810	.07904	.99687	28
.02705	.99963	.04449	.99901	.06192	.99808	.07933	.99685	27
.02734	.99963	.04478	.99900	.06221	.99806	.07962	.99683	26
.02763	.99962	.04507	.99898	.06250	.99804	.07991	.99680	25
.02792	.99961	.04536	.99897	.06279	.99803	.08020	.99678	24
.02821	.99960	.04565	.99896	.06308	.99801	.08049	.99676	23
.02850	.99959	.04594	.99894	.06337	.99799	.08078	.99673	22
.02879	.99959	.04623	.99893	.06366	.99797	.08107	.99671	21
.02908	.99958	.04653	.99892	.06395	.99795	.08136	.99668	20
.02938	.99957	.04682	.99890	.06424	.99793	.08165	.99666	19
.02967	.99956	.04711	.99889	.06453	.99792	.08194	.99664	18
.02996	.99955	.04740	.99888	.06482	.99790	.08223	.99661	17
.03025	.99954	.04769	.99886	.06511	.99788	.08252	.99659	16
.03054	.99953	.04798	.99885	.06540	.99786	.08281	.99657	15
.03083	.99952	.04827	.99883	.06569	.99784	.08310	.99654	14
.03112	.99952	.04856	.99882	.06598	.99782	.08339	.99652	13
.03141	.99951	.04885	.99881	.06627	.99780	.08368	.99649	12
.03170	.99950	.04914	.99879	.06656	.99778	.08397	.99647	11
.03199	.99949	.04943	.99878	.06685	.99776	.08426	.99644	10
.03228	.99948	.04972	.99876	.06714	.99774	.08455	.99642	9
.03257	.99947	.05001	.99875	.06743	.99772	.08484	.99639	8
.03286	.99946	.05030	.99873	.06773	.99770	.08513	.99637	7
.03316	.99945	.05059	.99872	.06802	.99768	.08542	.99635	6
.03345	.99944	.05088	.99870	.06831	.99766	.08571	.99632	5
.03374	.99943	.05117	.99869	.06860	.99764	.08600	.99630	4
.03403	.99942	.05146	.99867	.06889	.99762	.08629	.99627	3
.03432	.99941	.05175	.99866	.06918	.99760	.08658	.99625	2
.03461	.99940	.05205	.99864	.06947	.99758	.08687	.99622	1
.03490	.99939	.05234	.99863	.06976	.99756	.08716	.99619	0
Cosine	Sine	Cosine	Sine	Cosine	Sine	Cosine	Sine	′
88°		87°		86°		85°		

′	5°		6°		7°		8°	
	Sine	Cosine	Sine	Cosine	Sine	Cosine	Sine	Cosine
0	.08716	.99619	.10453	.99452	.12187	.99255	.13917	.99027
1	.08745	.99617	.10482	.99449	.12216	.99251	.13946	.99023
2	.08774	.99614	.10511	.99446	.12245	.99248	.13975	.99019
3	.08803	.99612	.10540	.99443	.12274	.99244	.14004	.99015
4	.08831	.99609	.10569	.99440	.12302	.99240	.14033	.99011
5	.08860	.99607	.10597	.99437	.12331	.99237	.14061	.99006
6	.08889	.99604	.10626	.99434	.12360	.99233	.14090	.99002
7	.08918	.99602	.10655	.99431	.12389	.99230	.14119	.98998
8	.08947	.99599	.10684	.99428	.12418	.99226	.14148	.98994
9	.08976	.99596	.10713	.99424	.12447	.99222	.14177	.98990
10	.09005	.99594	.10742	.99421	.12476	.99219	.14205	.98986
11	.09034	.99591	.10771	.99418	.12504	.99215	.14234	.98982
12	.09063	.99588	.10800	.99415	.12533	.99211	.14263	.98978
13	.09092	.99586	.10829	.99412	.12562	.99208	.14292	.98973
14	.09121	.99583	.10858	.99409	.12591	.99204	.14320	.98969
15	.09150	.99580	.10887	.99406	.12620	.99200	.14349	.98965
16	.09179	.99578	.10916	.99402	.12649	.99197	.14378	.98961
17	.09208	.99575	.10945	.99399	.12678	.99193	.14407	.98957
18	.09237	.99572	.10973	.99396	.12706	.99189	.14436	.98953
19	.09266	.99570	.11002	.99393	.12735	.99186	.14464	.98948
20	.09295	.99567	.11031	.99390	.12764	.99182	.14493	.98944
21	.09324	.99564	.11060	.99386	.12793	.99178	.14522	.98940
22	.09353	.99562	.11089	.99383	.12822	.99175	.14551	.98936
23	.09382	.99559	.11118	.99380	.12851	.99171	.14580	.98931
24	.09411	.99556	.11147	.99377	.12880	.99167	.14608	.98927
25	.09440	.99553	.11176	.99374	.12908	.99163	.14637	.98923
26	.09469	.99551	.11205	.99370	.12937	.99160	.14666	.98919
27	.09498	.99548	.11234	.99367	.12966	.99156	.14695	.98914
28	.09527	.99545	.11263	.99364	.12995	.99152	.14723	.98910
29	.09556	.99542	.11291	.99360	.13024	.99148	.14752	.98906
30	.09585	.99540	.11320	.99357	.13053	.99144	.14781	.98902
31	.09614	.99537	.11349	.99354	.13081	.99141	.14810	.98897
32	.09642	.99534	.11378	.99351	.13110	.99137	.14838	.98893
33	.09671	.99531	.11407	.99347	.13139	.99133	.14867	.98889
34	.09700	.99528	.11436	.99344	.13168	.99129	.14896	.98884
35	.09729	.99526	.11465	.99341	.13197	.99125	.14925	.98880
36	.09758	.99523	.11494	.99337	.13226	.99122	.14954	.98876
37	.09787	.99520	.11523	.99334	.13254	.99118	.14982	.98871
38	.09816	.99517	.11552	.99331	.13283	.99114	.15011	.98867
39	.09845	.99514	.11580	.99327	.13312	.99110	.15040	.98863
40	.09874	.99511	.11609	.99324	.13341	.99106	.15069	.98858
41	.09903	.99508	.11638	.99320	.13370	.99102	.15097	.98854
42	.09932	.99506	.11667	.99317	.13399	.99098	.15126	.98849
43	.09961	.99503	.11696	.99314	.13427	.99094	.15155	.98845
44	.09990	.99500	.11725	.99310	.13456	.99091	.15184	.98841
45	.10019	.99497	.11754	.99307	.13485	.99087	.15212	.98836
46	.10048	.99494	.11783	.99303	.13514	.99083	.15241	.98832
47	.10077	.99491	.11812	.99300	.13543	.99079	.15270	.98827
48	.10106	.99488	.11840	.99297	.13572	.99075	.15299	.98823
49	.10135	.99485	.11869	.99293	.13600	.99071	.15327	.98818
50	.10164	.99482	.11898	.99290	.13629	.99067	.15356	.98814
51	.10192	.99479	.11927	.99286	.13658	.99063	.15385	.98809
52	.10221	.99476	.11956	.99283	.13687	.99059	.15414	.98805
53	.10250	.99473	.11985	.99279	.13716	.99055	.15442	.98800
54	.10279	.99470	.12014	.99276	.13744	.99051	.15471	.98796
55	.10308	.99467	.12043	.99272	.13773	.99047	.15500	.98791
56	.10337	.99464	.12071	.99269	.13802	.99043	.15529	.98787
57	.10366	.99461	.12100	.99265	.13831	.99039	.15557	.98782
58	.10395	.99458	.12129	.99262	.13860	.99035	.15586	.98778
59	.10424	.99455	.12158	.99258	.13889	.99031	.15615	.98773
60	.10453	.99452	.12187	.99255	.13917	.99027	.15643	.98769
′	Cosine	Sine	Cosine	Sine	Cosine	Sine	Cosine	Sine
	84°		83°		82°		81°	

9°		10°		11°		12°		
Sine	Cosine	Sine	Cosine	Sine	Cosine	Sine	Cosine	′
.15643	.98769	.17365	.98481	.19081	.98163	.20791	.97815	60
.15672	.98764	.17393	.98476	.19109	.98157	.20820	.97809	59
.15701	.98760	.17422	.98471	.19138	.98152	.20848	.97803	58
.15730	.98755	.17451	.98466	.19167	.98146	.20877	.97797	57
.15758	.98751	.17479	.98461	.19195	.98140	.20905	.97791	56
.15787	.98746	.17508	.98455	.19224	.98135	.20933	.97784	55
.15816	.98741	.17537	.98450	.19252	.98129	.20962	.97778	54
.15845	.98737	.17565	.98445	.19281	.98124	.20990	.97772	53
.15873	.98732	.17594	.98440	.19309	.98118	.21019	.97766	52
.15902	.98728	.17623	.98435	.19338	.98112	.21047	.97760	51
.15931	.98723	.17651	.98430	.19366	.98107	.21076	.97754	50
.15959	.98718	.17680	.98425	.19395	.98101	.21104	.97748	49
.15988	.98714	.17708	.98420	.19423	.98096	.21132	.97742	48
.16017	.98709	.17737	.98414	.19452	.98090	.21161	.97735	47
.16046	.98704	.17766	.98409	.19481	.98084	.21189	.97729	46
.16074	.98700	.17794	.98404	.19509	.98079	.21218	.97723	45
.16103	.98695	.17823	.98399	.19538	.98073	.21246	.97717	44
.16132	.98690	.17852	.98394	.19566	.98067	.21275	.97711	43
.16160	.98689	.17880	.98389	.19595	.98061	.21303	.97705	42
.16189	.98681	.17909	.98383	.19623	.98056	.21331	.97698	41
.16218	.98676	.17937	.98378	.19652	.98050	.21360	.97692	40
.16246	.98671	.17966	.98373	.19680	.98044	.21388	.97686	39
.16275	.98667	.17995	.98368	.19709	.98039	.21417	.97680	38
.16304	.98662	.18023	.98362	.19737	.98033	.21445	.97673	37
.16333	.98657	.18052	.98357	.19766	.98027	.21474	.97667	36
.16361	.98652	.18081	.98352	.19794	.98021	.21502	.97661	35
.16390	.98648	.18109	.98347	.19823	.98016	.21530	.97655	34
.16419	.98643	.18138	.98341	.19851	.98010	.21559	.97648	33
.16447	.98638	.18166	.98336	.19880	.98004	.21587	.97642	32
.16476	.98633	.18195	.98331	.19908	.97987	.21616	.97636	31
.16505	.98629	.18224	.98325	.19937	.97992	.21644	.97630	30
.16533	.98624	.18252	.98320	.19965	.97987	.21672	.97623	29
.16562	.98619	.18281	.98315	.19994	.97981	.21701	.97617	28
.16591	.98614	.18309	.98310	.20022	.97975	.21729	.97611	27
.16620	.98609	.18338	.98304	.20051	.97969	.21758	.97604	26
.16648	.98604	.18367	.98299	.20079	.97963	.21786	.97598	25
.16677	.98600	.18395	.98294	.20108	.97958	.21814	.97592	24
.16706	.98595	.18424	.98288	.20136	.97952	.21843	.97585	23
.16734	.98590	.18452	.98283	.20165	.97946	.21871	.97579	22
.16763	.98585	.18481	.98277	.20193	.97940	.21899	.97573	21
.16792	.98580	.18509	.98272	.20222	.97934	.21928	.97566	20
.16820	.98575	.18538	.98267	.20250	.97928	.21956	.97560	19
.16849	.98570	.18567	.98261	.20279	.97922	.21985	.97553	18
.16878	.98565	.18595	.98256	.20307	.97916	.22013	.97547	17
.16906	.98561	.18624	.98250	.20336	.97910	.22041	.97541	16
.16935	.98556	.18652	.98245	.20364	.97905	.22070	.97534	15
.16964	.98551	.18681	.98240	.20393	.97899	.22098	.97528	14
.16992	.98546	.18710	.98234	.20421	.97893	.22126	.97521	13
.17021	.98541	.18738	.98229	.20450	.97887	.22155	.97515	12
.17050	.98536	.18767	.98223	.20478	.97881	.22183	.97508	11
.17078	.98531	.18795	.98218	.20507	.97875	.22212	.97501	10
.17107	.98526	.18824	.98212	.20535	.97869	.22240	.97496	9
.17136	.98521	.18852	.98207	.20563	.97863	.22268	.97489	8
.17164	.98516	.18881	.98201	.20592	.97857	.22297	.97483	7
.17193	.98511	.18910	.98196	.20620	.97851	.22325	.97476	6
.17222	.98506	.18938	.98190	.20649	.97845	.22353	.97470	5
.17250	.98501	.18967	.98185	.20677	.97839	.22382	.97463	4
.17279	.98496	.18995	.98179	.20706	.97833	.22410	.97457	3
.17308	.98491	.19024	.98174	.20734	.97827	.22438	.97450	2
.17336	.98486	.19052	.98168	.20763	.97821	.22467	.97444	1
.17365	.98481	.19081	.98163	.20791	.97815	.22495	.97437	0
Cosine	Sine	Cosine	Sine	Cosine	Sine	Cosine	Sine	′
80°		79°		78°		77°		

′	13°		14°		15°		16°	
	Sine	Cosine	Sine	Cosine	Sine	Cosine	Sine	Cosine
0	.22495	.97437	.24192	.97030	.25882	.96593	.27564	.96126
1	.22523	.97430	.24220	.97023	.25910	.96585	.27592	.96118
2	.22552	.97424	.24249	.97015	.25938	.96578	.27620	.96110
3	.22580	.97417	.24277	.97008	.25966	.96570	.27648	.96102
4	.22608	.97411	.24305	.97001	.25994	.96562	.27676	.96094
5	.22637	.97404	.24333	.96994	.26022	.96555	.27704	.96086
6	.22665	.97398	.24362	.96987	.26050	.96547	.27731	.96078
7	.22693	.97391	.24390	.96980	.26079	.96540	.27759	.96070
8	.22722	.97384	.24418	.96973	.26107	.96532	.27787	.96062
9	.22750	.97378	.24446	.96966	.26135	.96524	.27815	.96054
10	.22778	.97371	.24474	.96959	.26163	.96517	.27843	.96046
11	.22807	.97365	.24503	.96952	.26191	.96509	.27871	.96037
12	.22835	.97358	.24531	.96945	.26219	.96502	.27899	.96029
13	.22863	.97351	.24559	.96937	.26247	.96494	.27927	.96021
14	.22892	.97345	.24587	.96930	.26275	.96486	.27955	.96013
15	.22920	.97338	.24615	.96923	.26303	.96479	.27983	.96005
16	.22948	.97331	.24644	.96916	.26331	.96471	.28011	.95997
17	.22977	.97325	.24672	.96909	.26359	.96463	.28039	.95989
18	.23005	.97318	.24700	.96902	.26387	.96456	.28067	.95981
19	.23033	.97311	.24728	.96894	.26415	.96448	.28095	.95972
20	.23062	.97304	.24756	.96887	.26443	.96440	.28123	.95964
21	.23090	.97298	.24784	.96880	.26471	.96433	.28150	.95956
22	.23118	.97291	.24813	.96873	.26500	.96425	.28178	.95948
23	.23146	.97284	.24841	.96866	.26528	.96417	.28206	.95940
24	.23175	.97278	.24869	.96858	.26556	.96410	.28234	.95931
25	.23203	.97271	.24897	.96851	.26584	.96402	.28262	.95923
26	.23231	.97264	.24925	.96844	.26612	.96394	.28290	.95915
27	.23260	.97257	.24954	.96837	.26640	.96386	.28318	.95907
28	.23288	.97251	.24982	.96829	.26668	.96379	.28346	.95898
29	.23316	.97244	.25010	.96822	.26696	.96371	.28374	.95890
30	.23345	.97237	.25038	.96815	.26724	.96363	.28402	.95882
31	.23373	.97230	.25066	.96807	.26752	.96355	.28429	.95874
32	.23401	.97223	.25094	.96800	.26780	.96347	.28457	.95865
33	.23429	.97217	.25122	.96793	.26808	.96340	.28485	.95857
34	.23458	.97210	.25151	.96786	.26836	.96332	.28513	.95849
35	.23486	.97203	.25179	.96778	.26864	.96324	.28541	.95841
36	.23514	.97196	.25207	.96771	.26892	.96316	.28569	.95832
37	.23542	.97189	.25235	.96764	.26920	.96308	.28597	.95824
38	.23571	.97182	.25263	.96756	.26948	.96301	.28625	.95816
39	.23599	.97176	.25291	.96749	.26976	.96293	.28652	.95807
40	.23627	.97169	.25320	.96742	.27004	.96285	.28680	.95799
41	.23656	.97162	.25348	.96734	.27032	.96277	.28708	.95791
42	.23684	.97155	.25376	.96727	.27060	.96269	.28736	.95782
43	.23712	.97148	.25404	.96719	.27088	.96261	.28764	.95774
44	.23740	.97141	.25432	.96712	.27116	.96253	.28792	.95766
45	.23769	.97134	.25460	.96705	.27144	.96246	.28820	.95757
46	.23797	.97127	.25488	.96697	.27172	.96238	.28847	.95749
47	.23825	.97120	.25516	.96690	.27200	.96230	.28875	.95740
48	.23853	.97113	.25545	.96682	.27228	.96222	.28903	.95732
49	.23882	.97106	.25573	.96675	.27256	.96214	.28931	.95724
50	.23910	.97100	.25601	.96667	.27284	.96206	.28959	.95715
51	.23938	.97093	.25629	.96660	.27312	.96198	.28987	.95707
52	.23966	.97086	.25657	.96653	.27340	.96190	.29015	.95698
53	.23995	.97079	.25685	.96645	.27368	.96182	.29042	.95690
54	.24023	.97072	.25713	.96638	.27396	.96174	.29070	.95681
55	.24051	.97065	.25741	.96630	.27424	.96166	.29098	.95673
56	.24079	.97058	.25769	.96623	.27452	.96158	.29126	.95664
57	.24108	.97051	.25798	.96615	.27480	.96150	.29154	.95656
58	.24136	.97044	.25826	.96608	.27508	.96142	.29182	.95647
59	.24164	.97037	.25854	.96600	.27536	.96134	.29209	.95639
60	.24192	.97030	.25882	.96593	.27564	.96126	.29237	.95630
′	Cosine	Sine	Cosine	Sine	Cosine	Sine	Cosine	Sine
	76°		75°		74°		73°	

17°		18°		19°		20°		
Sine	Cosine	Sine	Cosine	Sine	Cosine	Sine	Cosine	′
.29237	.95630	.30902	.95106	.32557	.94552	.34202	.93969	60
.29265	.95622	.30929	.95097	.32584	.94542	.34229	.93959	59
.29293	.95613	.30957	.95088	.32612	.94533	.34257	.93949	58
.29321	.95605	.30985	.95079	.32639	.94523	.34284	.93939	57
.29348	.95596	.31012	.95070	.32667	.94514	.34311	.93929	56
.29376	.95588	.31040	.95061	.32694	.94504	.34339	.93919	55
.29404	.95579	.31068	.95052	.32722	.94495	.34366	.93909	54
.29432	.95571	.31095	.95043	.32749	.94485	.34393	.93899	53
.29460	.95562	.31123	.95033	.32777	.94476	.34421	.93889	52
.29487	.95554	.31151	.95024	.32804	.94466	.34448	.93879	51
.29515	.95545	.31178	.95015	.32832	.94457	.34475	.93869	50
.29543	.95536	.31206	.95006	.32859	.94447	.34503	.93859	49
.29571	.95528	.31233	.94997	.32887	.94438	.34530	.93849	48
.29599	.95519	.31261	.94988	.32914	.94428	.34557	.93839	47
.29626	.95511	.31289	.94979	.32942	.94418	.34584	.93829	46
.29654	.95502	.31316	.94970	.32969	.94409	.34612	.93819	45
.29682	.95493	.31344	.94961	.32997	.94399	.34639	.93809	44
.29710	.95485	.31372	.94952	.33024	.94390	.34666	.93799	43
.29737	.95476	.31399	.94943	.33051	.94380	.34694	.93789	42
.29765	.95467	.31427	.94933	.33079	.94370	.34721	.93779	41
.29793	.95459	.31454	.94924	.33106	.94361	.34748	.93769	40
.29821	.95450	.31482	.94915	.33134	.94351	.34775	.93759	39
.29849	.95441	.31510	.94906	.33161	.94342	.34803	.93748	38
.29876	.95433	.31537	.94897	.33189	.94332	.34830	.93738	37
.29904	.95424	.31565	.94888	.33216	.94322	.34857	.93728	36
.29932	.95415	.31593	.94878	.33244	.94313	.34884	.93718	35
.29960	.95407	.31620	.94869	.33271	.94303	.34912	.93708	34
.29987	.95398	.31648	.94860	.33298	.94293	.34939	.93698	33
.30015	.95389	.31675	.94851	.33326	.94284	.34966	.93688	32
.30043	.95380	.31703	.94842	.33353	.94274	.34993	.93677	31
.30071	.95372	.31730	.94832	.33381	.94264	.35021	.93667	30
.30098	.95363	.31758	.94823	.33408	.94254	.35048	.93657	29
.30126	.95354	.31786	.94814	.33436	.94245	.35075	.93647	28
.30154	.95345	.31813	.94805	.33463	.94235	.35102	.93637	27
.30182	.95337	.31841	.94795	.33490	.94225	.35130	.93626	26
.30209	.95328	.31868	.94786	.33518	.94215	.35157	.93616	25
.30237	.95319	.31896	.94777	.33545	.94206	.35184	.93606	24
.30265	.95310	.31923	.94768	.33573	.94196	.35211	.93596	23
.30292	.95301	.31951	.94758	.33600	.94186	.35239	.93585	22
.30320	.95293	.31979	.94749	.33627	.94176	.35266	.93575	21
.30348	.95284	.32006	.94740	.33655	.94167	.35293	.93565	20
.30376	.95275	.32034	.94730	.33682	.94157	.35320	.93555	19
.30403	.95266	.32061	.94721	.33710	.94147	.35347	.93544	18
.30431	.95257	.32089	.94712	.33737	.94137	.35375	.93534	17
.30459	.95248	.32116	.94702	.33764	.94127	.35402	.93524	16
.30486	.95240	.32144	.94693	.33792	.94118	.35429	.93514	15
.30514	.95231	.32171	.94684	.33819	.94108	.35456	.93503	14
.30542	.95222	.32199	.94674	.33846	.94098	.35484	.93493	13
.30570	.95213	.32227	.94665	.33874	.94088	.35511	.93483	12
.30597	.95204	.32254	.94656	.33901	.94078	.35538	.93472	11
.30625	.95195	.32282	.94646	.33929	.94068	.35565	.93462	10
.30653	.95186	.32309	.94637	.33956	.94058	.35592	.93452	9
.30680	.95177	.32337	.94627	.33983	.94049	.35619	.93441	8
.30708	.95168	.32364	.94618	.34011	.94039	.35647	.93431	7
.30736	.95159	.32392	.94609	.34038	.94029	.35674	.93420	6
.30763	.95150	.32419	.94599	.34065	.94019	.35701	.93410	5
.30791	.95142	.32447	.94590	.34093	.94009	.35728	.93400	4
.30819	.95133	.32474	.94580	.34120	.93999	.35755	.93389	3
.30846	.95124	.32502	.94571	.34147	.93989	.35782	.93379	2
.30874	.95115	.32529	.94561	.34175	.93979	.35810	.93368	1
.30902	.95106	.32557	.94552	.34202	.93969	.35837	.93358	0
Cosine	Sine	Cosine	Sine	Cosine	Sine	Cosine	Sine	′
72°		71°		70°		69°		

	21°		22°		23°		24°	
	Sine	Cosine	Sine	Cosine	Sine	Cosine	Sine	Cosine
0	.35837	.93358	.37461	.92718	.39073	.92050	.40674	.91355
1	.35864	.93348	.37488	.92707	.39100	.92039	.40700	.91343
2	.35891	.93337	.37515	.92697	.39127	.92028	.40727	.91331
3	.35918	.93327	.37542	.92686	.39153	.92016	.40753	.91319
4	.35945	.93316	.37569	.92675	.39180	.92005	.40780	.91307
5	.35973	.93306	.37595	.92664	.39207	.91994	.40806	.91295
6	.36000	.93295	.37622	.92653	.39234	.91982	.40833	.91283
7	.36027	.93285	.37649	.92642	.39260	.91971	.40860	.91272
8	.36054	.93274	.37676	.92631	.39287	.91959	.40886	.91260
9	.36081	.93264	.37703	.92620	.39314	.91948	.40913	.91248
10	.36108	.93253	.37730	.92609	.39341	.91936	.40939	.91236
11	.36135	.93243	.37757	.92598	.39367	.91925	.40966	.91224
12	.36162	.93232	.37784	.92587	.39394	.91914	.40992	.91212
13	.36190	.93222	.37811	.92576	.39421	.91902	.41019	.91200
14	.36217	.93211	.37838	.92565	.39448	.91891	.41045	.91188
15	.36244	.93201	.37865	.92554	.39474	.91879	.41072	.91176
16	.36271	.93190	.37892	.92543	.39501	.91868	.41098	.91164
17	.36298	.93180	.37919	.92532	.39528	.91856	.41125	.91152
18	.36325	.93169	.37946	.92521	.39555	.91845	.41151	.91140
19	.36352	.93159	.37973	.92510	.39581	.91833	.41178	.91128
20	.36379	.93148	.37999	.92499	.39608	.91822	.41204	.91116
21	.36406	.93137	.38026	.92488	.39635	.91810	.41231	.91104
22	.36434	.93127	.38053	.92477	.39661	.91799	.41257	.91092
23	.36461	.93116	.38080	.92466	.39688	.91787	.41284	.91080
24	.36488	.93106	.38107	.92455	.39715	.91775	.41310	.91068
25	.36515	.93095	.38134	.92444	.39741	.91764	.41337	.91056
26	.36542	.93084	.38161	.92432	.39768	.91752	.41363	.91044
27	.36569	.93074	.38188	.92421	.39795	.91741	.41390	.91032
28	.36596	.93063	.38215	.92410	.39822	.91729	.41416	.91020
29	.36623	.93052	.38241	.92399	.39848	.91718	.41443	.91008
30	.36650	.93042	.38268	.92388	.39875	.91706	.41469	.90996
31	.36677	.93031	.38295	.92377	.39902	.91694	.41496	.90984
32	.36704	.93020	.38322	.92366	.39928	.91683	.41522	.90972
33	.36731	.93010	.38349	.92355	.39955	.91671	.41549	.90960
34	.36758	.92999	.38376	.92343	.39982	.91660	.41575	.90948
35	.36785	.92988	.38403	.92332	.40008	.91648	.41602	.90936
36	.36812	.92978	.38430	.92321	.40035	.91636	.41628	.90924
37	.36839	.92967	.38456	.92310	.40062	.91625	.41655	.90911
38	.36867	.92956	.38483	.92299	.40088	.91613	.41681	.90899
39	.36894	.92945	.38510	.92287	.40115	.91601	.41707	.90887
40	.36921	.92935	.38537	.92276	.40141	.91590	.41734	.90875
41	.36948	.92924	.38564	.92265	.40168	.91578	.41760	.90863
42	.36975	.92913	.38591	.92254	.40195	.91566	.41787	.90851
43	.37002	.92902	.38617	.92243	.40221	.91555	.41813	.90839
44	.37029	.92892	.38644	.92231	.40248	.91543	.41840	.90826
45	.37056	.92881	.38671	.92220	.40275	.91531	.41866	.90814
46	.37083	.92870	.38698	.92209	.40301	.91519	.41892	.90802
47	.37110	.92859	.38725	.92198	.40328	.91508	.41919	.90790
48	.37137	.92849	.38752	.92186	.40355	.91496	.41945	.90778
49	.37164	.92838	.38778	.92175	.40381	.91484	.41972	.90766
50	.37191	.92827	.38805	.92164	.40408	.91472	.41998	.90753
51	.37218	.92816	.38832	.92152	.40434	.91461	.42024	.90741
52	.37245	.92805	.38859	.92141	.40461	.91449	.42051	.90729
53	.37272	.92794	.38886	.92130	.40488	.91437	.42077	.90717
54	.37299	.92784	.38912	.92119	.40514	.91425	.42104	.90704
55	.37326	.92773	.38939	.92107	.40541	.91414	.42130	.90692
56	.37353	.92762	.38966	.92096	.40567	.91402	.42156	.90680
57	.37380	.92751	.38993	.92085	.40594	.91390	.42183	.90668
58	.37407	.92740	.39020	.92073	.40621	.91378	.42209	.90655
59	.37434	.92729	.39046	.92062	.40647	.91366	.42235	.90643
60	.37461	.92718	.39073	.92050	.40674	.91355	.42262	.90631
′	Cosine	Sine	Cosine	Sine	Cosine	Sine	Cosine	Sine
	68°		67°		66°		65°	

25°		26°		27°		28°		
Sine	Cosine	Sine	Cosine	Sine	Cosine	Sine	Cosine	′
.42262	.90631	.43837	.89879	.45399	.89101	.46947	.88295	60
.42288	.90618	.43863	.89867	.45425	.89087	.46973	.88281	59
.42315	.90606	.43889	.89854	.45451	.89074	.46999	.88267	58
.42341	.90594	.43916	.89841	.45477	.89061	.47024	.88254	57
.42367	.90582	.43942	.89828	.45503	.89048	.47050	.88240	56
.42394	.90569	.43968	.89816	.45529	.89035	.47076	.88226	55
.42420	.90557	.43994	.89803	.45554	.89021	.47101	.88213	54
.42446	.90545	.44020	.89790	.45580	.89008	.47127	.88199	53
.42473	.90532	.44046	.89777	.45606	.88995	.47153	.88185	52
.42499	.90520	.44072	.89764	.45632	.88981	.47178	.88172	51
.42525	.90507	.44098	.89752	.45658	.88968	.47204	.88158	50
.42552	.90495	.44124	.89739	.45684	.88955	.47229	.88144	49
.42578	.90483	.44151	.89726	.45710	.88942	.47255	.88130	48
.42604	.90470	.44177	.89713	.45736	.88928	.47281	.88117	47
.42631	.90458	.44203	.89700	.45762	.88915	.47306	.88103	46
.42657	.90446	.44229	.89687	.45787	.88902	.47332	.88089	45
.42683	.90433	.44255	.89674	.45813	.88888	.47358	.88075	44
.42709	.90421	.44281	.89662	.45839	.88875	.47383	.88062	43
.42736	.90408	.44307	.89649	.45865	.88862	.47409	.88048	42
.42762	.90396	.44333	.89636	.45891	.88848	.47434	.88034	41
.42788	.90383	.44359	.89623	.45917	.88835	.47460	.88020	40
.42815	.90371	.44385	.89610	.45942	.88822	.47486	.88006	39
.42841	.90358	.44411	.89597	.45968	.88808	.47511	.87993	38
.42867	.90346	.44437	.89584	.45994	.88795	.47537	.87979	37
.42894	.90334	.44464	.89571	.46020	.88782	.47562	.87965	36
.42920	.90321	.44490	.89558	.46046	.88768	.47588	.87951	35
.42946	.90309	.44516	.89545	.46072	.88755	.47614	.87937	34
.42972	.90296	.44542	.89532	.46097	.88741	.47639	.87923	33
.42999	.90284	.44568	.89519	.46123	.88728	.47665	.87909	32
.43025	.90271	.44594	.89506	.46149	.88715	.47690	.87896	31
.43051	.90259	.44620	.89493	.46175	.88701	.47716	.87882	30
.43077	.90246	.44646	.89480	.46201	.88688	.47741	.87868	29
.43104	.90233	.44672	.89467	.46226	.88674	.47767	.87854	28
.43130	.90221	.44698	.89454	.46252	.88661	.47793	.87840	27
.43156	.90208	.44724	.89441	.46278	.88647	.47818	.87826	26
.43182	.90196	.44750	.89428	.46304	.88634	.47844	.87812	25
.43209	.90183	.44776	.89415	.46330	.88620	.47869	.87798	24
.43235	.90171	.44802	.89402	.46355	.88607	.47895	.87784	23
.43261	.90158	.44828	.89389	.46381	.88593	.47920	.87770	22
.43287	.90146	.44854	.89376	.46407	.88580	.47946	.87756	21
.43313	.90133	.44880	.89363	.46433	.88566	.47971	.87743	20
.43340	.90120	.44906	.89350	.46458	.88553	.47997	.87729	19
.43366	.90108	.44932	.89337	.46484	.88539	.48022	.87715	18
.43392	.90095	.44958	.89324	.46510	.88526	.48048	.87701	17
.43418	.90082	.44984	.89311	.46536	.88512	.48073	.87687	16
.43445	.90070	.45010	.89298	.46561	.88499	.48099	.87673	15
.43471	.90057	.45036	.89285	.46587	.88485	.48124	.87659	14
.43497	.90045	.45062	.89272	.46613	.88472	.48150	.87645	13
.43523	.90032	.45088	.89259	.46639	.88458	.48175	.87631	12
.43549	.90019	.45114	.89245	.46664	.88445	.48201	.87617	11
.43575	.90007	.45140	.89232	.46690	.88431	.48226	.87603	10
.43602	.89994	.45166	.89219	.46716	.88417	.48252	.87589	9
.43628	.89981	45192	.89206	.46742	.88404	.48277	.87575	8
.43654	.89968	.45218	.89193	.46767	.88390	.48303	.87561	7
.43680	.89956	.45243	.89180	.46793	.88377	.48328	.87546	6
.43706	.89943	.45269	.89167	.46819	.88363	.48354	.87532	5
.43733	.89930	.45295	.89153	.46844	.88349	.48379	.87518	4
.43759	.89918	.45321	.89140	.46870	.88336	.48405	.87504	3
.43785	.89905	.45347	.89127	.46896	.88322	.48430	.87490	2
.43811	.89892	.45373	.89114	.46921	.88308	.48456	.87476	1
.43837	.89879	.45399	.89101	.46947	.88295	.48481	.87462	0
Cosine	Sine	Cosine	Sine	Cosine	Sine	Cosine	Sine	′
64°		63°		62°		61°		

′	29° Sine	29° Cosine	30° Sine	30° Cosine	31° Sine	31° Cosine	32° Sine	32° Cosine
0	.48481	.87462	.50000	.86603	.51504	.85717	.52992	.84805
1	.48506	.87448	.50025	.86588	.51529	.85702	.53017	.84789
2	.48532	.87434	.50050	.86573	.51554	.85687	.53041	.84774
3	.48557	.87420	.50076	.86559	.51579	.85672	.53066	.84759
4	.48583	.87406	.50101	.86544	.51604	.85657	.53091	.84743
5	.48608	.87391	.50126	.86530	.51628	.85642	.53115	.84728
6	.48634	.87377	.50151	.86515	.51653	.85627	.53140	.84712
7	.48659	.87363	.50176	.86501	.51678	.85612	.53164	.84697
8	.48684	.87349	.50201	.86486	.51703	.85597	.53189	.84681
9	.48710	.87335	.50227	.86471	.51728	.85582	.53214	.84666
10	.48735	.87321	.50252	.86457	.51753	.85567	.53238	.84650
11	.48761	.87306	.50277	.86442	.51778	.85551	.53263	.84635
12	.48786	.87292	.50302	.86427	.51803	.85536	.53288	.84619
13	.48811	.87278	.50327	.86413	.51828	.85521	.53312	.84604
14	.48837	.87264	.50352	.86398	.51852	.85506	.53337	.84588
15	.48862	.87250	.50377	.86384	.51877	.85491	.53361	.84573
16	.48888	.87235	.50403	.86369	.51902	.85476	.53386	.84557
17	.48913	.87221	.50428	.86354	.51927	.85461	.53411	.84542
18	.48938	.87207	.50453	.86340	.51952	.85446	.53435	.84526
19	.48964	.87193	.50478	.86325	.51977	.85431	.53460	.84511
20	.48989	.87178	.50503	.86310	.52002	.85416	.53484	.84495
21	.49014	.87164	.50528	.86295	.52026	.85401	.53509	.84480
22	.49040	.87150	.50553	.86281	.52051	.85385	.53534	.84464
23	.49065	.87136	.50578	.86266	.52076	.85370	.53558	.84448
24	.49090	.87121	.50603	.86251	.52101	.85355	.53583	.84433
25	.49116	.87107	.50628	.86237	.52126	.85340	.53607	.84417
26	.49141	.87093	.50654	.86222	.52151	.85325	.53632	.84402
27	49166	.87079	.50679	.86207	.52175	.85310	.53656	.84386
28	.49192	.87064	.50704	.86192	.52200	.85294	.53681	.84370
29	.49217	.87050	.50729	.86178	.52225	.85279	.53705	.84355
30	.49242	.87036	.50754	.86163	.52250	.85264	.53730	.84339
31	.49268	.87021	.50779	.86148	.52275	.85249	.53754	.84324
32	.49293	.87007	.50804	.86133	.52299	.85234	.53779	.84308
33	.49318	.86993	.50829	.86119	.52324	.85218	.53804	.84292
34	.49344	.86978	.50854	.86104	.52349	.85203	.53828	.84277
35	.49369	.86964	.50879	.86089	.52374	.85188	.53853	.84261
36	.49394	.86949	.50904	.86074	.52399	.85173	.53877	.84245
37	.49419	.86935	.50929	.86059	.52423	.85157	.53902	.84230
38	.49445	.86921	.50954	.86045	.52448	.85142	.53926	.84214
39	.49470	.86906	.50979	.86030	.52473	.85127	.53951	.84198
40	.49495	.86892	.51004	.86015	.52498	.85112	.53975	.84182
41	.49521	.86878	.51029	.86000	.52522	.85096	.54000	.84167
42	.49546	.86863	.51054	.85985	.52547	.85081	.54024	.84151
43	.49571	.86849	.51079	.85970	.52572	.85066	.54049	.84135
44	.49596	.86834	.51104	.85956	.52597	.85051	.54073	.84120
45	.49622	.86820	.51129	.85941	.52621	.85035	.54097	.84104
46	.49647	.86805	.51154	.85926	.52646	.85020	.54122	.84088
47	.49672	.86791	.51179	.85911	.52671	.85005	.54146	.84072
48	.49697	.86777	.51204	.85896	.52696	.84989	.54171	.84057
49	.49723	.86762	.51229	.85881	.52720	.84974	.54195	.84041
50	.49748	.86748	.51254	.85866	.52745	.84959	.54220	.84025
51	.49773	.86733	.51279	.85851	.52770	.84943	.54244	.84009
52	.49798	.86719	.51304	.85836	.52794	.84928	.54269	.83994
53	.49824	.86704	.51329	.85821	.52819	.84913	.54293	.83978
54	.49849	.86690	.51354	.85806	.52844	.84897	.54317	.83962
55	.49874	.86675	.51379	.85792	.52869	.84882	.54342	.83946
56	.49899	.86661	.51404	.85777	.52893	.84866	.54366	.83930
57	.49924	.86646	.51429	.85762	.52918	.84851	.54391	.83915
58	.49950	.86632	.51454	.85747	.52943	.84836	.54415	.83899
59	.49975	.86617	.51479	.85732	.52967	.84820	.54440	.83883
60	.50000	.86603	.51504	.85717	.52992	.84805	.54464	.83867
′	Cosine 60°	Sine 60°	Cosine 59°	Sine 59°	Cosine 58°	Sine 58°	Cosine 57°	Sine 57°

′	33°		34°		35°		36°		′
	Sine	Cosine	Sine	Cosine	Sine	Cosine	Sine	Cosnie	
0	.54464	.83867	.55919	.82904	.57358	.81915	.58779	.80902	60
1	.54488	.83851	.55943	.82887	.57381	.81899	.58802	.80885	59
2	.54513	.83835	.55968	.82871	.57405	.81882	.58826	.80867	58
3	.54537	.83819	.55992	.82855	.57429	.81865	.58849	.80850	57
4	.54561	.83804	.56016	.82839	.57453	.81848	.58873	.80833	56
5	.54586	.83788	.56040	.82822	.57477	.81832	.58896	.80816	55
6	.54610	.83772	.56064	.82806	.57501	.81815	.58920	.80799	54
7	.54635	.83756	.56088	.82790	.57524	.81798	.58943	.80782	53
8	.54659	.83740	.56112	.82773	.57548	.81782	.58967	.80765	52
9	.54683	.83724	.56136	.82757	.57572	.81765	.58990	.80748	51
10	.54708	.83708	.56160	.82741	.57596	.81748	.59014	.80730	50
11	.54732	83692	.56184	.82724	.57619	.81731	.59037	.80713	49
12	.54756	.83676	.56208	.82708	.57643	.81714	.59061	.80696	48
13	.54781	.83660	.56232	.82692	.57667	.81698	.59084	.80679	47
14	.54805	.83645	.56256	.82675	.57691	.81681	.59108	.80662	46
15	.54829	.83629	.56280	.82659	.57715	.81664	.59131	.80644	45
16	.54854	.83613	.56305	.82643	.57738	.81647	.59154	.80627	44
17	.54878	.83597	.56329	.82626	.57762	.81631	.59178	.80610	43
18	.54902	.83581	.56353	.82610	.57786	.81614	.59201	.80593	42
19	.54927	.83565	.56377	.82593	.57810	.81597	.59225	.80576	41
20	.54951	.83549	.56401	.82577	.57833	.81580	.59248	.80558	40
21	.54975	.83533	.56425	.82561	.57857	.81563	.59272	.80541	39
22	.54999	.83517	.56449	.82544	.57881	.81546	.59295	.80524	38
23	.55024	.83501	.56473	.82528	.57904	.81530	.59318	.80507	37
24	.55048	.83485	.56497	.82511	.57928	.81513	.59342	.80489	36
25	.55072	.83469	.56521	.82495	.57952	.81496	.59365	.80472	35
26	.55097	.83453	.56545	.82478	.57976	.81479	.59389	.80455	34
27	.55121	.83437	.56569	.82462	.57999	.81462	.59412	.80438	33
28	.55145	.83421	.56593	.82446	.58023	.81445	.59436	.80420	32
29	.55169	.83405	.56617	.82429	.58047	.81428	.59459	.80403	31
30	.55194	.83389	.56641	.82413	.58070	.81412	.59482	.80386	30
31	.55218	.83373	.56665	.82396	.58094	.81395	.59506	.80368	29
32	.55242	.83356	.56689	.82340	.58118	.81378	.59529	.80351	28
33	.55266	.83340	.56713	.82363	.58141	.81361	.59552	.80334	27
34	.55291	.83324	.56736	.82347	.58165	.81344	.59576	.80316	26
35	.55315	.83308	.56760	.82330	.58189	.81327	.59599	.80299	25
36	.55339	.83292	.56784	.82314	.58212	.81310	.59622	.80282	24
37	.55363	.83276	.56808	.82297	.58236	.81293	.59646	.80264	23
38	.55388	.83260	.56832	.82281	.58260	.81276	.59669	.80247	22
39	.55412	.83244	.56856	.82264	.58283	.81259	.59693	.80230	21
40	.55436	.83228	.56880	.82248	.58307	.81242	.59716	.80212	20
41	.55460	.83212	.56904	.82231	.58330	.81225	.59739	.80195	19
42	.55484	.83195	.56928	.82214	.58354	.81208	.59763	.80178	18
43	.55509	.83179	.56952	.82198	.58378	.81191	.59786	.80160	17
44	.55533	.83163	.56976	.82181	.58401	.81174	.59809	.80143	16
45	.55557	.83147	.57000	.82165	.58425	.81157	.59832	.80125	15
46	.55581	.83131	.57024	.82148	.58449	.81140	.59856	.80108	14
47	.55605	.83115	.57047	.82132	.58472	.81123	.59879	.80091	13
48	.55630	.83098	.57071	.82115	.58496	.81106	.59902	.80073	12
49	.55654	.83082	.57095	.82098	.58519	.81089	.59926	.80056	11
50	.55678	.83066	.57119	.82082	.58543	.81072	.59949	.80038	10
51	.55702	.83050	.57143	.82065	.58567	.81055	.59972	.80021	9
52	.55726	.83034	.57167	.82048	.58590	.81038	.59995	.80003	8
53	.55750	.83017	.57191	.82032	.58614	.81021	.60019	.79986	7
54	.55775	.83001	.57215	.82015	.58637	.81004	.60042	.79968	6
55	.55799	.82985	.57238	.81999	.58661	.80987	.60065	.79951	5
56	.55823	.82969	.57262	.81982	.58684	.80970	.60089	.79934	4
57	.55847	.82953	.57286	.81965	.58708	.80953	.60112	.79916	3
58	.55871	.82936	.57310	.81949	.58731	.80936	.60135	.79899	2
59	.55895	.82920	.57334	.81932	.58755	.80919	.60158	.79881	1
60	.55919	.82904	.57358	.81915	.58779	.80902	.60182	.79864	0
′	Cosine	Sine	Cosine	Sine	Cosine	Sine	Cosine	Sine	′
	56°		55°		54°		53°		

′	37°		38°		39°		40°		′
	Sine	Cosine	Sine	Cosine	Sine	Cosine	Sine	Cosine	
0	.60182	.79864	.61566	.78801	.62932	.77715	.64279	.76604	6
1	.60205	.79846	.61589	.78783	.62955	.77696	.64301	.76586	5
2	.60228	.79829	.61612	.78765	.62977	.77678	.64323	.76567	5
3	.60251	.79811	.61635	.78747	.63000	.77660	.64346	.76548	5
4	.60274	.79793	.61658	.78729	.63022	.77641	.64368	.76530	5
5	.60298	.79776	.61681	.78711	.63045	.77623	.64390	.76511	5
6	.60321	.79758	.61704	.78694	.63068	.77605	.64412	.76492	5
7	.60344	.79741	.61726	.78676	.63090	.77586	.64435	.76473	5
8	.60367	.79723	.61749	.78658	.63113	.77568	.64457	.76455	5
9	.60390	.79706	.61772	.78640	.63135	.77550	.64479	.76436	5
10	.60414	.79688	.61795	.78622	.63158	.77531	.64501	.76417	5
11	.60437	.79671	.61818	.78604	.63180	.77513	.64524	.76398	
12	.60460	.79653	.61841	.78586	.63203	.77494	.64546	.76380	
13	.60483	.79635	.61864	.78568	.63225	.77476	.64568	.76361	
14	.60506	.79618	.61887	.78550	.63248	.77458	.64590	.76342	
15	.60529	.79600	.61909	.78532	.63271	.77439	.64612	.76323	
16	.60553	.79583	.61932	.78514	.63293	.77421	.64635	.76304	
17	.60576	.79565	.61955	.78496	.63316	.77402	.64657	.76286	
18	.60599	.79547	.61978	.78478	.63338	.77384	.64679	.76267	
19	.60622	.79530	.62001	.78460	.63361	.77366	.64701	.76248	
20	.60645	.79512	.62024	.78442	.63383	.77347	.64723	.76229	
21	.60668	.79494	.62046	.78424	.63406	.77329	.64746	.76210	
22	.60691	.79477	.62069	.78405	.63428	.77310	.64768	.76192	
23	.60714	.79459	.62092	.78387	.63451	.77292	.64790	.76173	
24	.60738	.79441	.62115	.78369	.63473	.77273	.64812	.76154	
25	.60761	.79424	.62138	.78351	.63496	.77255	.64834	.76135	
26	.60784	.79406	.62160	.78333	.63518	.77236	.64856	.76116	
27	.60807	.79388	.62183	.78315	.63540	.77218	.64878	.76097	
28	.60830	.79371	.62206	.78297	.63563	.77199	.64901	.76078	
29	.60853	.79353	.62229	.78279	.63585	.77181	.64923	.76059	
30	.60876	.79335	.62251	.78261	.63608	.77162	.64945	.76041	
31	.60899	.79318	.62274	.78243	.63630	.77144	.64967	.76022	
32	.60922	.79300	.62297	.78225	.63653	.77125	.64989	.76003	
33	.60945	.79282	.62320	.78206	.63675	.77107	.65011	.75984	
34	.60968	.79264	.62342	.78188	.63698	.77088	.65033	.75965	
35	.60991	.79247	.62365	.78170	.63720	.77070	.65055	.75946	
36	.61015	.79229	.62388	.78152	.63742	.77051	.65077	.75927	
37	.61038	.79211	.62411	.78134	.63765	.77033	.65100	.75908	
38	.61061	.79193	.62433	.78116	.63787	.77014	.65122	.75889	
39	.61084	.79176	.62456	.78098	.63810	.76996	.65144	.75870	
40	.61107	.79158	.62479	.78079	.63832	.76977	.65166	.75851	
41	.61130	.79140	.62502	.78061	.63854	.76959	.65188	.75832	
42	.61153	.79122	.62524	.78043	.63877	.76940	.65210	.75813	
43	.61176	.79105	.62547	.78025	.63899	.76921	.65232	.75794	
44	.61199	.79087	.62570	.78007	.63922	.76903	.65254	.75775	
45	.61222	.79069	.62592	.77988	.63944	.76884	.65276	.75756	
46	.61245	.79051	.62615	.77970	.63966	.76866	.65298	.75738	
47	.61268	.79033	.62638	.77952	.63989	.76847	.65320	.75719	
48	.61291	.79016	.62660	.77934	.64011	.76828	.65342	.75700	
49	.61314	.78998	.62683	.77916	.64033	.76810	.65364	.75680	
50	.61337	.78980	.62706	.77897	.64056	.76791	.65386	.75661	
51	.61360	.78962	.62728	.77879	.64078	.76772	.65408	.75642	
52	.61383	.78944	.62751	.77861	.64100	.76754	.65430	.75623	
53	.61406	.78926	.62774	.77843	.64123	.76735	.65452	.75604	
54	.61429	.78908	.62796	.77824	.64145	.76717	.65474	.75585	
55	.61451	.78891	.62819	.77806	.64167	.76698	.65496	.75566	
56	.61474	.78873	.62842	.77788	.64190	.76679	.65518	.75547	
57	.61497	.78855	.62864	.77769	.64212	.76661	.65540	.75528	
58	.61520	.78837	.62887	.77751	.64234	.76642	.65562	.75509	
59	.61543	.78819	.62909	.77733	.64256	.76623	.65584	.75490	
60	.61566	.78801	.62932	.77715	.64279	.76604	.65606	.75471	
′	Cosine	Sine	Cosine	Sine	Cosine	Sine	Cosine	Sine	′
	52°		51°		50°		49°		

′	41° Sine	41° Cosine	42° Sine	42° Cosine	43° Sine	43° Cosine	44° Sine	44° Cosine	′
0	.65606	.75471	.66913	.74314	.68200	.73135	.69466	.71934	60
1	.65628	.75452	.66935	.74295	.68221	.73116	.69487	.71914	59
2	.65650	.75433	.66956	.74276	.68242	.73096	.69508	.71894	58
3	.65672	.75414	.66978	.74256	.68264	.73076	.69529	.71873	57
4	.65694	.75395	.66999	.74237	.68285	.73056	.69549	.71853	56
5	.65716	.75375	.67021	.74217	.68306	.73036	.69570	.71833	55
6	.65738	.75356	.67043	.74198	.68327	.73016	.69591	.71813	54
7	.65759	.75337	.67064	.74178	.68349	.72996	.69612	.71792	53
8	.65781	.75318	.67086	.74159	.68370	.72976	.69633	.71772	52
9	.65803	.75299	.67107	.74139	.68391	.72957	.69654	.71752	51
10	.65825	.75280	.67129	.74120	.68412	.72937	.69675	.71732	50
11	.65847	.75261	.67151	.74100	.68434	.72917	.69696	.71711	49
12	.65869	.75241	.67172	.74080	.68455	.72897	.69717	.71691	48
13	.65891	.75222	.67194	.74061	.68476	.72877	.69737	.71671	47
14	.65913	.75203	.67215	.74041	.68497	.72857	.69758	.71650	46
15	.65935	.75184	.67237	.74022	.68518	.72837	.69779	.71630	45
16	.65956	.75165	.67258	.74002	.68539	.72817	.69800	.71610	44
17	.65978	.75146	.67280	.73983	.68561	.72797	.69821	.71590	43
18	.66000	.75126	.67301	.73963	.68582	.72777	.69842	.71569	42
19	.66022	.75107	.67323	.73944	.68603	.72757	.69862	.71549	41
20	.66044	.75088	.67344	.73924	.68624	.72737	.69883	.71529	40
21	.66066	.75069	.67366	.73904	.68645	.72717	.69904	.71508	39
22	.66088	.75050	.67387	.73885	.68666	.72697	.69925	.71488	38
23	.66109	.75030	.67409	.73865	.68688	.72677	.69946	.71468	37
24	.66131	.75011	.67430	.73846	.68709	.72657	.69966	.71447	36
25	.66153	.74992	.67452	.73826	.68730	.72637	.69987	.71427	35
26	.66175	.74973	.67473	.73806	.68751	.72617	.70008	.71407	34
27	.66197	.74953	.67495	.73787	.68772	.72597	.70029	.71386	33
28	.66218	.74934	.67516	.73767	.68793	.72577	.70049	.71366	32
29	.66240	.74915	.67538	.73747	.68814	.72557	.70070	.71345	31
30	.66262	.74896	.67559	.73728	.68835	.72537	.70091	.71325	30
31	.66284	.74876	.67580	.73708	.68857	.72517	.70112	.71305	29
32	.66306	.74857	.67602	.73688	.68878	.72497	.70132	.71284	28
33	.66327	.74838	.67623	.73669	.68899	.72477	.70153	.71264	27
34	.66349	.74818	.67645	.73649	.68920	.72457	.70174	.71243	26
35	.66371	.74799	.67666	.73629	.68941	.72437	.70195	.71223	25
36	.66393	.74780	.67688	.73610	.68962	.72417	.70215	.71203	24
37	.66414	.74760	.67709	.73590	.68983	.72397	.70236	.71182	23
38	.66436	.74741	.67730	.73570	.69004	.72377	.70257	.71162	22
39	.66458	.74722	.67752	.73551	.69025	.72357	.70277	.71141	21
40	.66480	.74703	.67773	.73531	.69046	.72337	.70298	.71121	20
41	.66501	.74683	.67795	.73511	.69067	.72317	.70319	.71100	19
42	.66523	.74664	.67816	.73491	.69088	.72297	.70339	.71080	18
43	.66545	.74644	.67837	.73472	.69109	.72277	.70360	.71059	17
44	.66566	.74625	.67859	.73452	.69130	.72257	.70381	.71039	16
45	.66588	.74606	.67880	.73432	.69151	.72236	.70401	.71019	15
46	.66610	.74586	.67901	.73413	.69172	.72216	.70422	.70998	14
47	.66632	.74567	.67923	.73393	.69193	.72196	.70443	.70978	13
48	.66653	.74548	.67944	.73373	.69214	.72176	.70463	.70957	12
49	.66675	.74528	.67965	.73353	.69235	.72156	.70484	.70937	11
50	.66697	.74509	.67987	.73333	.69256	.72136	.70505	.70916	10
51	.66718	.74489	.68008	.73314	.69277	.72116	.70525	.70896	9
52	.66740	.74470	.68029	.73294	.69298	.72095	.70546	.70875	8
53	.66762	.74451	.68051	.73274	.69319	.72075	.70567	.70855	7
54	.66783	.74431	.68072	.73254	.69340	.72055	.70587	.70834	6
55	.66805	.74412	.68093	.73234	.69361	.72035	.70608	.70813	5
56	.66827	.74392	.68115	.73215	.69382	.72015	.70628	.70793	4
57	.66848	.74373	.68136	.73195	.69403	.71995	.70649	.70772	3
58	.66870	.74353	.68157	.73175	.69424	.71974	.70670	.70752	2
59	.66891	.74334	.68179	.73155	.69445	.71954	.70690	.70731	1
60	.66913	.74314	.68200	.73135	.69466	.71934	.70711	.70711	0
	Cosine	Sine	Cosine	Sine	Cosine	Sine	Cosine	Sine	′
	48°		47°		46°		45°		

Natural Secants and Co-Secants

′	0° Sec.	0° Co-sec.	1° Sec.	1° Co-sec.	2° Sec.	2° Co-sec.	3° Sec.	3° Co-sec.
0	1	Infinite.	1.0001	57.299	1.0006	28.654	1.0014	19.107
1	1	3437.70	1.0001	56.359	1.0006	28.417	1.0014	19.002
2	1	1718.90	1.0002	55.450	1.0006	28.184	1.0014	18.897
3	1	1145.90	1.0002	54.570	1.0006	27.955	1.0014	18.794
4	1	859.44	1.0002	53.718	1.0006	27.730	1.0014	18.692
5	1	687.55	1.0002	52.891	1.0007	27.508	1.0014	18.591
6	1	572.96	1.0002	52.090	1.0007	27.290	1.0015	18.491
7	1	491.11	1.0002	51.313	1.0007	27.075	1.0015	18.393
8	1	429.72	1.0002	50.558	1.0007	26.864	1.0015	18.295
9	1	381.97	1.0002	49.826	1.0007	26.655	1.0015	18.198
10	1	343.77	1.0002	49.114	1.0007	26.450	1.0015	18.103
11	1	312.52	1.0002	48.422	1.0007	26.249	1.0015	18.008
12	1	286.48	1.0002	47.750	1.0007	26.050	1.0016	17.914
13	1	264.44	1.0002	47.096	1.0007	25.854	1.0016	17.821
14	1	245.55	1.0002	46.460	1.0008	25.661	1.0016	17.730
15	1	229.18	1.0002	45.840	1.0008	25.471	1.0016	17.639
16	1	214.86	1.0002	45.237	1.0008	25.284	1.0016	17.549
17	1	202.22	1.0002	44.650	1.0008	25.100	1.0016	17.460
18	1	190.99	1.0002	44.077	1.0008	24.918	1.0017	17.372
19	1	180.73	1.0003	43.520	1.0008	24.739	1.0017	17.285
20	1	171.89	1.0003	42.976	1.0008	24.562	1.0017	17.198
21	1	163.70	1.0003	42.445	1.0008	24.358	1.0017	17.113
22	1	156.26	1.0003	41.928	1.0008	24.216	1.0017	17.028
23	1	149.47	1.0003	41.423	1 0009	24.047	1.0017	16.944
24	1	143.24	1.0003	40.930	1.0009	23.880	1.0018	16.861
25	1	137.51	1.0003	40.448	1.0009	23.716	1.0018	16.779
26	1	132.22	1.0003	39.978	1.0009	23.553	1.0018	16.698
27	1	127.32	1.0003	39.518	1.0009	23.393	1.0018	16.617
28	1	122.78	1.0003	39.069	1.0009	23.235	1.0018	16.538
29	1	118.54	1.0003	38.631	1.0009	23.079	1.0018	16.459
30	1	114.59	1.0003	38.201	1.0009	22.925	1.0019	16.380
31	1	110.90	1.0003	37.782	1.0010	22.774	1.0019	16.303
32	1	107.43	1.0003	37.371	1.0010	22.624	1.0019	16.226
33	1	104.17	1.0004	36.969	1.0010	22.476	1.0019	16.150
34	1	101.11	1.0004	36.576	1.0010	22.330	1.0019	16.075
35	1	98.223	1.0004	36.191	1.0010	22.186	1.0019	16.000
36	1	95.495	1.0004	35.814	1.0010	22.044	1.0020	15.926
37	1	92.914	1.0004	35.445	1.0010	21.904	1.0020	15.853
38	1.0001	92.469	1.0004	35.084	1.0010	21.765	1.0020	15.780
39	1.0001	88.149	1.0004	34.729	1.0011	21.629	1.0020	15.708
40	1.0001	85.946	1.0004	34.382	1.0011	21.494	1.0020	15.637
41	1.0001	83.849	1.0004	34.042	1.0011	21.360	1.0021	15.566
42	1.0001	81.853	1.0004	33.708	1.0011	21.228	1.0021	15.496
43	1.0001	79.950	1.0004	33.381	1.0011	21.098	1.0021	15.427
44	1.0001	78.133	1.0004	33.060	1.0011	20.970	1.0021	15.358
45	1.0001	76.396	1.0005	32.745	1.0011	20.843	1.0021	15.290
46	1.0001	74.736	1.0005	32.437	1.0012	20.717	1.0022	15.222
47	1.0001	73.146	1.0005	32.134	1.0012	20.593	1.0022	15.155
48	1.0001	71.622	1.0005	31.836	1.0012	20.471	1.0022	15.089
49	1.0001	71.160	1.0005	31.544	1.0012	20.350	1.0022	15.023
50	1.0001	68.757	1.0005	31.257	1.0012	20.230	1.0022	14.958
51	1.0001	67.409	1.0005	30.976	1.0012	20.112	1.0023	14.893
52	1.0001	66.113	1.0005	30.699	1.0012	19.995	1.0023	14.829
53	1.0001	64.866	1.0005	30.428	1.0013	19.880	1.0023	14.765
54	1.0001	63.664	1.0005	30.161	1.0013	19.766	1.0023	14.702
55	1.0001	62.507	1.0005	29.899	1.0013	19.653	1.0023	14.640
56	1.0001	61.391	1.0006	29.641	1.0013	19.541	1.0024	14.578
57	1.0001	61.314	1.0006	29.388	1.0013	19.431	1.0024	14.517
58	1.0001	59.274	1.0006	29.139	1.0013	19.322	1.0024	14.456
59	1.0001	58.270	1.0006	28.894	1.0013	19.214	1.0024	14.395
60	1.0001	57.299	1.0006	28.654	1.0014	19.107	1.0024	14.335
′	89° Co-sec.	89° Sec.	88° Co-sec.	88° Sec.	87° Co-sec.	87° Sec.	86° Co-sec.	86° Sec.

4° Sec.	4° Co-sec.	5° Sec.	5° Co-sec.	6° Sec.	6° Co-sec.	7° Sec.	7° Co-sec.	′
1.0024	14.335	1.0038	11.474	1.0055	9.5668	1.0075	8.2055	60
1.0025	14.276	1.0038	11.436	1.0055	9.5404	1.0075	8.1861	59
1.0025	14.217	1.0039	11.398	1.0056	9.5141	1.0076	8.1668	58
1.0025	14.159	1.0039	11.360	1.0056	9.4880	1.0076	8.1476	57
1.0025	14.101	1.0039	11.323	1.0056	9.4620	1.0076	8.1285	56
1.0025	14.043	1.0039	11.286	1.0057	9.4362	1.0077	8.1094	55
1.0026	13.986	1.0040	11.249	1.0057	9.4105	1.0077	8.0905	54
1.0026	13.930	1.0040	11.213	1.0057	9.3850	1.0078	8.0717	53
1.0026	13.874	1.0040	11.176	1.0057	9.3596	1.0078	8.0529	52
1.0026	13.818	1.0040	11.140	1.0058	9.3343	1.0078	8.0342	51
1.0026	13.763	1.0041	11.104	1.0058	9.3092	1.0079	8.0156	50
1.0027	13.708	1.0041	11.069	1.0058	9.2842	1.0079	7.9971	49
1.0027	13.654	1.0041	11.033	1.0059	9.2593	1.0079	7.9787	48
1.0027	13.600	1.0041	10.988	1.0059	9.2346	1.0080	7.9604	47
1.0027	13.547	1.0042	10.963	1.0059	9.2100	1.0080	7.9421	46
1.0027	13.494	1.0042	10.929	1.0060	9.1855	1.0080	7.9240	45
1.0028	13.441	1.0042	10.894	1.0060	9.1612	1.0081	7.9059	44
1.0028	13.389	1.0043	10.860	1.0060	9.1370	1.0081	7.8879	43
1.0028	13.337	1.0043	10.826	1.0061	9.1129	1.0082	7.8700	42
1.0028	13.286	1.0043	10.792	1.0061	9.0890	1.0082	7.8522	41
1.0029	13.235	1.0043	10.758	1.0061	9.0651	1.0082	7.8344	40
1.0029	13.184	1.0044	10.725	1.0062	9.0414	1.0083	7.8168	39
1.0029	13 134	1.0044	10.692	1 0062	9.0179	1.0083	7.7992	38
1.0029	13.084	1.0044	10.659	1.0062	8.9944	1.0084	7.7817	37
1.0029	13.034	1.0044	10.626	1.0063	8.9711	1.0084	7.7642	36
1.0030	12.985	1.0045	10.593	1.0063	8.9479	1.0084	7.7469	35
1.0030	12.937	1.0045	10.561	1.0063	8.9248	1.0085	7.7296	34
1.0030	12.888	1.0045	10.529	1.0064	8.9018	1.0085	7.7124	33
1.0030	12.840	1.0046	10.497	1.0064	8.8790	1.0085	7.6953	32
1.0031	12.793	1.0046	10.465	1.0064	8.8563	1.0086	7.6783	31
1.0031	12.745	1.0046	10.433	1.0065	8.8337	1.0086	7.6613	30
1.0031	12.698	1.0046	10.402	1.0065	8.8112	1.0087	7.6444	29
1.0031	12.652	1.0047	10.371	1.0065	8.7888	1.0087	7.6276	28
1.0032	12.606	1.0047	10.340	1.0066	8.7665	1.0087	7.6108	27
1.0032	12.560	1.0047	10.309	1.0066	8.7444	1.0088	7.5942	26
1.0032	12.514	1.0048	10.278	1.0066	8.7223	1.0088	7.5776	25
1.0032	12.469	1.0048	10.248	1.0067	8.7004	1.0089	7.5611	24
1.0032	12.424	1.0048	10.217	1.0067	8.6786	1.0089	7.5446	23
1.0033	12.379	1.0048	10.187	1.0067	8.6569	1.0089	7.5282	22
1.0033	12.335	1.0049	10.157	1.0068	8.6353	1.0090	7.5119	21
1.0033	12.291	1.0049	10.127	1.0068	8.6138	1·0090	7.4957	20
1.0033	12.248	1.0049	10.098	1.0068	8.5924	1.0090	7.4795	19
1.0034	12.204	1.0050	10.068	1.0069	8.5711	1.0091	7.4634	18
1.0034	12.161	1.0050	10.039	1.0069	8.5499	1.0091	7.4474	17
1.0034	12.118	1.0050	10.010	1.0069	8.5289	1.0092	7.4315	16
1.0034	12.076	1.0050	9.9812	1.0070	8.5079	1.0092	7.4156	15
1.0035	12.034	1.0051	9.9525	1.0070	8.4871	1.0092	7.3998	14
1.0035	11.992	1.0051	9.9239	1.0070	8.4663	1.0093	7.3840	13
1.0035	11.950	1.0051	9.8955	1.0071	8.4457	1.0093	7.3683	12
1.0035	11.909	1.0052	9.8672	1.0071	8.4251	1.0094	7.3527	11
1.0036	11.868	1.0052	9.8391	1.0071	8.4046	1.0094	7.3372	10
1.0036	11.828	1.0052	9.8112	1.0072	8.3843	1.0094	7.3217	9
1.0036	11.787	1.0053	9.7834	1.0072	8.3640	1.0095	7.3063	8
1.0036	11.747	1.0053	9.7558	1.0073	8.3439	1.0095	7.2909	7
1.0037	11.707	1.0053	9.7283	1.0073	8.3238	1.0096	7.2757	6
1.0037	11.668	1.0053	9.7010	1.0073	8.3039	1.0096	7.2604	5
1.0037	11.628	1.0054	9.6739	1.0074	8.2840	1.0097	7.2453	4
1.0037	11.589	1.0054	9.6469	1.0074	8.2642	1.0097	7.2302	3
1.0038	11.550	1.0054	9.6200	1.0074	8.2446	1.0097	7.2152	2
1.0038	11.512	1.0055	9.5933	1.0075	8.2250	1.0098	7.2002	1
1.0038	11.474	1.0055	9.5668	1.0075	8.2055	1.0098	7.1853	0
Co-sec.	Sec.	Co-sec.	Sec.	Co-sec.	Sec.	Co-sec.	Sec.	′
85°		84°		83°		82°		

	8°		9°		10°		11°	
′	Sec.	Co-sec.	Sec.	Co-sec.	Sec.	Co.sec.	Sec.	Co-sec.
0	1.0098	7.1853	1.0125	6.3924	1.0154	5.7588	1.0187	5.2408
1	1.0099	7.1704	1.0125	6.3807	1.0155	5.7493	1.0188	5.2330
2	1.0099	7.1557	1.0125	6.3690	1.0155	5.7398	1.0188	5.2252
3	1.0099	7.1409	1.0126	6.3574	1.0156	5.7304	1.0189	5.2174
4	1.0100	7.1263	1.0126	6.3458	1.0156	5.7210	1.0189	5.2097
5	1.0100	7.1117	1.0127	6.3343	1.0157	5.7117	1.0190	5.2019
6	1.0101	7.0972	1.0127	6.3228	1.0157	5.7023	1.0191	5.1942
7	1.0101	7.0827	1.0128	6.3113	1.0158	5.6930	1.0191	5.1865
8	1.0102	7.0683	1.0128	6.2999	1.0158	5.6838	1.0192	5.1788
9	1.0102	7.0539	1.0129	6.2885	1.0159	5.6745	1.0192	5.1712
10	1.0102	7.0396	1.0129	6.2772	1.0159	5.6653	1.0193	5.1636
11	1.0103	7.0254	1.0130	6.2659	1.0160	5.6561	1.0193	5.1560
12	1.0103	7.0112	1.0130	6.2546	1.0160	5.6470	1.0194	5.1484
13	1.0104	6.9971	1.0131	6.2434	1.0161	5.6379	1.0195	5.1409
14	1.0104	6.9830	1.0131	6.2322	1.0162	5.6288	1.0195	5.1333
15	1.0104	6.9690	1.0132	6.2211	1.0162	5.6197	1.0196	5.1258
16	1.0105	6.9550	1.0132	6.2100	1.0163	5.6107	1.0196	5.1183
17	1.0105	6.9411	1.0133	6.1990	1.0163	5.6017	1.0197	5.1109
18	1.0106	6.9273	1.0133	6.1880	1.0164	5.5928	1.0198	5.1034
19	1.0106	6.9135	1.0134	6.1770	1.0164	5.5838	1.0198	5.0960
20	1.0107	6.8998	1.0134	6.1661	1.0165	5.5749	1.0199	5.0886
21	1.0107	6.8861	1.0135	6.1552	1.0165	5.5660	1.0199	5.0812
22	1.0107	6.8725	1.0135	6.1443	1.0166	5.5572	1.0200	5.0739
23	1.0108	6.8589	1.0136	6.1335	1.0166	5.5484	1.0201	5.0666
24	1.0108	6.8454	1.0136	6.1227	1.0167	5.5396	1.0201	5.0593
25	1.0109	6.8320	1.0136	6.1120	1.0167	5.5308	1.0202	5.0520
26	1.0109	6.8185	1.0137	6.1013	1.0168	5.5221	1.0202	5.0447
27	1.0110	6.8052	1.0137	6.0906	1.0169	5.5134	1.0203	5.0375
28	1.0110	6.7919	1.0138	6.0800	1.0169	5.5047	1.0204	5.0302
29	1.0111	6.7787	1.0138	6.0694	1.0170	5.4960	1.0204	5.0230
30	1.0111	6.7655	1.0139	6.0588	1.0170	5.4874	1.0205	5.0158
31	1.0111	6.7523	1.0139	6.0483	1.0171	5.4788	1.0205	5.0087
32	1.0112	6.7392	1.0140	6.0379	1.0171	5.4702	1.0206	5.0015
33	1.0112	6.7262	1.0140	6.0274	1.0172	5.4617	1.0207	4.9944
34	1.0113	6.7132	1.0141	6.0170	1.0172	5.4532	1.0207	4.9873
35	1.0113	6.7003	1.0141	6.0066	1.0173	5.4447	1.0208	4.9802
36	1.0114	6.6874	1.0142	5.9963	1.0174	5.4362	1.0208	4.9732
37	1.0114	6.6745	1.0142	5.9860	1.0174	5.4278	1.0209	4.9661
38	1.0115	6.6617	1.0143	5.9758	1.0175	5.4194	1.0210	4.9591
39	1.0115	6.6490	1.0143	5.9655	1.0175	5.4110	1.0210	4.9521
40	1.0115	6.6363	1.0144	5.9554	1.0176	5.4026	1.0211	4.9452
41	1.0116	6.6237	1.0144	5.9452	1.0176	5.3943	1.0211	4.9382
42	1.0116	6.6111	1.0145	5.9351	1.0177	5.3860	1.0212	4.9313
43	1.0117	6.5985	1.0145	5.9250	1.0177	5.3777	1.0213	4.9243
44	1.0117	6.5860	1.0146	5.9150	1.0178	5.3695	1.0213	4.9175
45	1.0118	6.5736	1.0146	5.9049	1.0179	5.3612	1.0214	4.9106
46	1.0118	6.5612	1.0147	5.8950	1.0179	5.3530	1.0215	4.9037
47	1.0119	6.5488	1.0147	5.8850	1.0180	5.3449	1.0215	4.8969
48	1.0119	6.5365	1.0148	5.8751	1.0180	5.3367	1.0216	4.8901
49	1.0119	6.5243	1.0148	5.8652	1.0181	5.3286	1.0216	4.8833
50	1.0120	6.5121	1.0149	5.8554	1.0181	5.3205	1.0217	4.8765
51	1.0120	6.4999	1.0150	5.8456	1.0182	5.3124	1.0218	4.8697
52	1.0121	6.4878	1.0150	5.8358	1.0182	5.3044	1.0218	4.8630
53	1.0121	6.4757	1.0151	5.8261	1.0183	5.2963	1.0219	4.8563
54	1.0122	6.4637	1.0151	5.8163	1.0184	5.2883	1.0220	4.8496
55	1.0122	6.4517	1.0152	5.8067	1.0184	5.2803	1.0220	4.8429
56	1.0123	6.4398	1.0152	5.7970	1.0185	5.2724	1.0221	4.8362
57	1.0123	6.4279	1.0153	5.7874	1.0185	5.2645	1.0221	4.8296
58	1.0124	6.4160	1.0153	5.7778	1.0186	5.2566	1.0222	4.8229
59	1.0124	6.4042	1.0154	5.7683	1.0186	5.2487	1.0223	4.8163
60	1.0125	6.3924	1.0154	5.7588	1.0187	5.2408	1.0223	4.8097
′	Co-sec.	Sec.	Co-sec.	Sec.	Co-sec.	Sec.	Co-sec.	Sec.
	81°		80°		79°		78°	

′	12° Sec.	12° Co-sec.	13° Sec.	13° Co-sec.	14° Sec.	14° Co-sec.	15° Sec.	15° Co-sec.	′
0	1.0223	4.8097	1.0263	4.4454	1.0306	4.1336	1.0353	3.8637	60
1	1.0224	4.8032	1.0264	4.4398	1.0307	4.1287	1.0353	3.8595	59
2	1.0225	4.7966	1.0264	4.4342	1.0308	4.1239	1.0354	3.8553	58
3	1.0225	4.7901	1.0265	4.4287	1.0308	4.1191	1.0355	3.8512	57
4	1.0226	4.7835	1.0266	4.4231	1.0309	4.1144	1.0356	3.8470	56
5	1.0226	4.7770	1.0266	4.4176	1.0310	4.1096	1.0357	3.8428	55
6	1.0227	4.7706	1.0267	4.4121	1.0311	4.1048	1.0358	3.8387	54
7	1.0228	4.7641	1.0268	4.4065	1.0311	4.1001	1.0358	3.8346	53
8	1.0228	4.7576	1.0268	4.4011	1.0312	4.0953	1.0359	3.8304	52
9	1.0229	4.7512	1.0269	4.3956	1.0313	4.0906	1.0360	3.8263	51
10	1.0230	4.7448	1.0270	4.3910	1.0314	4.0859	1.0361	3.8222	50
11	1.0230	4.7384	1.0271	4.3847	1.0314	4.0812	1.0362	3.8181	49
12	1.0231	4.7320	1.0271	4.3792	1.0315	4.0765	1.0362	3.8140	48
13	1.0232	4.7257	1.0272	4.3738	1.0316	4.0718	1.0363	3.8100	47
14	1.0232	4.7193	1.0273	4.3684	1.0317	4.0672	1.0364	3.8059	46
15	1.0233	4.7130	1.0273	4.3630	1.0317	4.0625	1.0365	3.8018	45
16	1.0234	4.7067	1.0274	4.3576	1.0318	4.0579	1.0366	3.7978	44
17	1.0234	4.7004	1.0275	4.3522	1.0319	4.0532	1.0367	3.7937	43
18	1.0235	4.6942	1.0276	4.3469	1.0320	4.0486	1.0367	3.7897	42
19	1.0235	4.6879	1.0276	4.3415	1.0320	4.0440	1.0368	3.7857	41
20	1.0236	4.6817	1.0277	4.3362	1.0321	4.0394	1.0369	3.7816	40
21	1.0237	4.6754	1.0278	4.3309	1.0322	4.0348	1.0370	3.7776	39
22	1.0237	4.6692	1.0278	4.3256	1.0323	4.0302	1.0371	3.7736	38
23	1.0238	4.6631	1.0279	4.3203	1.0323	4.0256	1.0371	3.7697	37
24	1.0239	4.6569	1.0280	4.3150	1.0324	4.0211	1.0372	3.7657	36
25	1.0239	4.6507	1.0280	4.3098	1.0325	4.0165	1.0373	3.7617	35
26	1.0240	4.6446	1.0281	4.3045	1.0326	4.0120	1.0374	3.7577	34
27	1.0241	4.6385	1.0282	4.2993	1.0327	4.0074	1.0375	3.7538	33
28	1.0241	4.6324	1.0283	4.2941	1.0327	4.0029	1.0376	3.7498	32
29	1.0242	4.6263	1.0283	4.2888	1.0328	3.9984	1.0376	3.7459	31
30	1.0243	4.6202	1.0284	4.2836	1.0329	3.9939	1.0377	3.7420	30
31	1.0243	4.6142	1.0285	4.2785	1.0330	3.9894	1.0378	3.7380	29
32	1.0244	4.6081	1.0285	4.2733	1.0330	3.9850	1.0379	3.7341	28
33	1.0245	4.6021	1.0286	4.2681	1.0331	3.9805	1.0380	3.7302	27
34	1.0245	4.5961	1.0287	4.2630	1.0332	3.9760	1.0381	3.7263	26
35	1.0246	4.5901	1.0288	4.2579	1.0333	3.9716	1.0382	3.7224	25
36	1.0247	4.5841	1.0288	4.2527	1.0334	3.9672	1.0382	3.7186	24
37	1.0247	4.5782	1.0289	4.2476	1.0334	3.9627	1.0383	3.7147	23
38	1.0248	4.5722	1.0290	4.2425	1.0335	3.9583	1.0384	3.7108	22
39	1.0249	4.5663	1.0291	4.2375	1.0336	3.9539	1.0385	3.7070	21
40	1.0249	4.5604	1.0291	4.2324	1.0337	3.9495	1.0386	3.7031	20
41	1.0250	4.5545	1.0292	4.2273	1.0338	3.9451	1.0387	3.6993	19
42	1.0251	4.5486	1.0293	4.2223	1.0338	3.9408	1.0387	3.6955	18
43	1.0251	4.5428	1.0293	4.2173	1.0339	3.9364	1.0388	3.6917	17
44	1.0252	4.5369	1.0294	4.2122	1.0340	3.9320	1.0389	3.6878	16
45	1.0253	4.5311	1.0295	4.2072	1.0341	3.9277	1.0390	3.6840	15
46	1.0253	4.5253	1.0296	4.2022	1.0341	3.9234	1.0391	3.6802	14
47	1.0254	4.5195	1.0296	4.1972	1.0342	3.9199	1.0392	3.6765	13
48	1.0255	4.5137	1.0297	4.1923	1.0343	3.9147	1.0393	3.6727	12
49	1.0255	4.5079	1.0298	4.1873	1.0344	3.9104	1.0393	3.6689	11
50	1.0256	4.5021	1.0299	4.1824	1.0345	3.9061	1.0394	3.6651	10
51	1.0257	4.4964	1.0299	4.1774	1.0345	3.9018	1.0395	3.6614	9
52	1.0257	4.4907	1.0300	4.1725	1.0346	3.8976	1.0396	3.6576	8
53	1.0258	4.4850	1.0301	4.1676	1.0347	3.8933	1.0397	3.6539	7
54	1.0259	4.4793	1.0302	4.1627	1.0348	3.8990	1.0398	3.6502	6
55	1.0260	4.4736	1.0302	4.1578	1.0349	3.8848	1.0399	3.6464	5
56	1.0260	4.4679	1.0303	4.1529	1.0349	3.8805	1.0399	3.6427	4
57	1.0261	4.4623	1.0304	4.1481	1.0350	3.8763	1.0400	3.6390	3
58	1.0262	4.4566	1.0305	4.1432	1.0351	3.8721	1.0401	3.6353	2
59	1.0262	4.4510	1.0305	4.1384	1.0352	3.8679	1.0402	3.6316	1
60	1.0263	4.4454	1.0306	4.1336	1.0353	3.8637	1.0403	3.6279	0
	77° Co-sec.	77° Sec.	76° Co-sec.	76° Sec.	75° Co-sec.	75° Sec.	74° Co-sec.	74° Sec.	′

′	16° Sec.	16° Co-sec.	17° Sec.	17° Co-sec.	18° Sec.	18° Co-sec.	19° Sec.	19° Co-sec.
0	1.0403	3.6279	1.0457	3.4203	1.0515	3.2361	1.0576	3.0715
1	1.0404	3.6243	1.0458	3.4170	1.0516	3.2332	1.0577	3.0690
2	1.0405	3.6206	1.0459	3.4138	1.0517	3.2303	1.0578	3.0664
3	1.0406	3.6169	1.0460	3.4106	1.0518	3.2274	1.0579	3.0638
4	1.0406	3.6133	1.0461	3.4073	1.0519	3.2245	1.0580	3.0612
5	1.0407	5.6096	1.0461	3.4041	1.0520	3.2216	1.0581	3.0586
6	1.0408	3.6060	1.0462	3.4009	1.0521	3.2188	1.0582	3.0561
7	1.0409	3.6024	1.0463	3.3977	1.0522	3.2159	1.0584	3.0535
8	1.0410	3.5987	1.0464	3.3945	1.0523	3.2131	1.0585	3.0509
9	1.0411	3.5951	1.0465	3.3913	1.0524	3.2102	1.0586	3.0484
10	1.0412	3.5915	1.0466	3.3881	1.0525	3.2074	1.0587	3.0458
11	1.0413	3.5879	1.0467	3.3849	1.0526	3.2045	1.0588	3.0433
12	1.0413	3.5843	1.0468	3.3817	1.0527	3.2017	1.0589	3.0407
13	1.0414	3.5807	1.0469	3.3785	1.0528	3.1989	1.0590	3.0382
14	1.0415	3.5772	1.0470	3.3754	1.0529	3.1960	1.0591	3.0357
15	1.0416	3.5736	1.0471	3.3722	1.0530	3.1932	1.0592	3.0331
16	1.0417	3.5700	1.0472	3.3690	1.0531	3.1904	1.0593	3.0306
17	1.0418	3.5665	1.0473	3.3659	1.0532	3.1876	1.0594	3.0281
18	1.0419	3.5629	1.0474	3.3627	1.0533	3.1848	1.0595	3.0256
19	1.0420	3.5594	1.0475	3.3596	1.0534	3.1820	1.0596	3.0231
20	1.0420	3.5559	1.0476	3.3565	1.0535	3.1792	1.0598	3.0206
21	1.0421	3.5523	1.0477	3.3534	1.0536	3.1764	1.0599	3.0181
22	1.0422	3.5488	1.0478	3.3502	1.0537	3.1736	1.0600	3.0156
23	1.0423	3.5453	1.0478	3.3471	1.0538	3.1708	1.0601	3.0131
24	1.0424	3.5418	1.0479	3.3440	1.0539	3.1681	1.0602	3.0106
25	1.0425	3.5383	1.0480	3.3409	1.0540	3.1653	1.0603	3.0081
26	1.0426	3.5348	1.0481	3.3378	1.0541	3.1625	1.0604	3.0056
27	1.0427	3.5313	1.0482	3.3347	1.0542	3.1598	1.0605	3.0031
28	1.0428	3.5279	1.0483	3.3316	1.0543	3.1570	1.0606	3.0007
29	1.0428	3.5244	1.0484	3.3286	1.0544	3.1543	1.0607	2.9982
30	1.0429	3.5209	1.0485	3.3255	1.0545	3.1515	1.0608	2.9957
31	1.0430	3.5175	1.0486	3.3224	1.0546	3.1488	1.0609	2.9933
32	1.0431	3.5140	1.0487	3.3194	1.0547	3.1461	1.0611	2.9908
33	1.0432	3.5106	1.0488	3.3163	1.0548	3.1433	1.0612	2.9884
34	1.0433	3.5072	1.0489	3.3133	1.0549	3.1406	1.0613	2.9859
35	1.0434	3.5037	1.0490	3.3102	1.0550	3.1379	1.0614	2.9835
36	1.0435	3.5003	1.0491	3.3072	1.0551	3.1352	1.0615	2.9810
37	1.0436	3.4969	1.0492	3.3042	1.0552	3.1325	1.0616	2.9786
38	1.0437	3.4935	1.0493	3.3011	1.0553	3.1298	1.0617	2.9762
39	1.0438	3.4901	1.0494	3.2981	1.0554	3.1271	1.0618	2.9738
40	1.0438	3.4867	1.0495	3.2951	1.0555	3.1244	1.0619	2.9713
41	1.0439	3.4833	1.0496	3.2921	1.0556	3.1217	1.0620	2.9689
42	1.0440	3.4799	1.0497	3.2891	1.0557	3.1190	1.0622	2.9665
43	1.0441	3.4766	1.0498	3.2861	1.0558	3.1163	1.0623	2.9641
44	1.0442	3.4732	1.0499	3.2831	1.0559	3.1137	1.0624	2.9617
45	1.0443	3.4698	1.0500	3.2801	1.0560	3.1110	1.0625	2.9593
46	1.0444	3.4665	1.0501	3.2772	1.0561	3.1083	1.0626	2.9569
47	1.0445	3.4632	1.0502	3.2742	1.0562	3.1057	1.0627	2.9545
48	1.0446	3.4598	1.0503	3.2712	1.0563	3.1030	1.0628	2.9521
49	1.0447	3.4565	1.0504	3.2683	1.0565	3.1004	1.0629	2.9497
50	1.0448	3.4532	1.0505	3.2653	1.0566	3.0977	1.0630	2.9474
51	1.0448	3.4498	1.0506	3.2624	1.0567	3.0951	1.0632	2.9450
52	1.0449	3.4465	1.0507	3.2594	1.0568	3.0925	1.0633	2.9426
53	1.0450	3.4432	1.0508	3.2565	1.0569	3.0898	1.0634	2.9402
54	1.0451	3.4399	1.0509	3.2535	1.0570	3.0872	1.0635	2.9379
55	1.0452	3.4366	1.0510	3.2506	1.0571	3.0846	1.0636	2.9355
56	1.0453	3.4334	1.0511	3.2477	1.0572	3.0820	1.0637	2.9332
57	1.0454	3.4301	1.0512	3.2448	1.0573	3.0793	1.0638	2.9308
58	1.0455	3.4268	1.0513	3.2419	1.0574	3.0767	1.0639	2.9285
59	1.0456	3.4236	1.0514	3.2390	1.0575	3.0741	1.0641	2.9261
60	1.0457	3.4203	1.0515	3.2361	1.0576	3.0715	1.0642	2.9238
′	Co-sec.	Sec.	Co-sec.	Sec.	Co-sec.	Sec.	Co-sec.	Sec.
	73°		72°		71°		70°	

′	20°		21°		22°		23°		′
	Sec.	Co-sec.	Sec.	Co-sec.	Sec.	Co-sec.	Sec.	Co-sec.	
0	1.0642	2.9238	1.0711	2.7904	1.0785	2.6695	1.0864	2.5593	60
1	1.0643	2.9215	1.0713	2.7883	1.0787	2.6675	1.0865	2.5575	59
2	1.0644	2.9191	1.0714	2.7862	1.0788	2.6656	1.0866	2.5558	58
3	1.0645	2.9168	1.0715	2.7841	1.0789	2.6637	1.0868	2.5540	57
4	1.0646	2.9145	1.0716	2.7820	1.0790	2.6618	1.0869	2.5523	56
5	1.0647	2.9122	1.0717	2.7799	1.0792	2.6599	1.0870	2.5506	55
6	1.0648	2.9098	1.0719	2.7778	1.0793	2.6580	1.0872	2.5488	54
7	1.0650	2.9075	1.0720	2.7757	1.0794	2.6561	1.0873	2.5471	53
8	1.0651	2.9052	1.0721	2.7736	1.0795	2.6542	1.0874	2.5453	52
9	1.0652	2.9029	1.0722	2.7715	1.0797	2.6523	1.0876	2.5436	51
10	1.0653	2.9006	1.0723	2.7694	1.0798	2.6504	1.0877	2.5419	50
11	1.0654	2.8983	1.0725	2.7674	1.0799	2.6485	1.0878	2.5402	49
12	1.0655	2.8960	1.0726	2.7653	1.0801	2.6466	1.0880	2.5384	48
13	1.0656	2.8937	1.0727	2.7632	1.0802	2.6447	1.0881	2.5367	47
14	1.0658	2.8915	1.0728	2.7611	1.0803	2.6428	1.0882	2.5350	46
15	1.0659	2.8892	1.0729	2.7591	1.0804	2.6410	1.0884	2.5333	45
16	1.0660	2.8869	1.0731	2.7570	1.0806	2.6391	1.0885	2.5316	44
17	1.0661	2.8846	1.0732	2.7550	1.0807	2.6372	1.0886	2.5299	43
18	1.0662	2.8824	1.0733	2.7529	1.0808	2.6353	1.0888	2.5281	42
19	1.0663	2.8801	1.0734	2.7509	1.0810	2.6335	1.0889	2.5264	41
20	1.0664	2.8778	1.0736	2.7488	1.0811	2.6316	1.0891	2.5247	40
21	1.0666	2.8756	1.0737	2.7468	1.0812	2.6297	1.0892	2.5230	39
22	1.0667	2.8733	1.0738	2.7447	1.0813	2.6279	1.0893	2.5213	38
23	1.0668	2.8711	1.0739	2.7427	1.0815	2.6260	1.0895	2.5196	37
24	1.0669	2.8688	1.0740	2.7406	1.0816	2.6242	1.0896	2.5179	36
25	1.0670	2.8666	1.0742	2.7386	1.0817	2.6223	1.0897	2.5163	35
26	1.0671	2.8644	1.0743	2.7366	1.0819	2.6205	1.0899	2.5146	34
27	1.0673	2.8621	1.0744	2.7346	1.0820	2.6186	1.0900	2.5129	33
28	1.0674	2.8599	1.0745	2.7325	1.0821	2.6168	1.0902	2.5112	32
29	1.0675	2.8577	1.0747	2.7305	1.0823	2.6150	1.0903	2.5095	31
30	1.0676	2.8554	1.0748	2.7285	1.0824	2.6131	1.0904	2.5078	30
31	1.0677	2.8532	1.0749	2.7265	1.0825	2.6113	1.0906	2.5062	29
32	1.0678	2.8510	1.0750	2.7245	1.0826	2.6095	1.0907	2.5045	28
33	1.0679	2.8488	1.0751	2.7225	1.0828	2.6076	1.0908	2.5028	27
34	1.0681	2.8466	1.0753	2.7205	1.0829	2.6058	1.0910	2.5011	26
35	1.0682	2.8444	1.0754	2.7185	1.0830	2.6040	1.0911	2.4995	25
36	1.0683	2.8422	1.0755	2.7165	1.0832	2.6022	1.0913	2.4978	24
37	1.0684	2.8400	1.0756	2.7145	1.0833	2.6003	1.0914	2.4961	23
38	1.0685	2.8378	1.0758	2.7125	1.0834	2.5985	1.0915	2.4945	22
39	1.0686	2.8356	1.0759	2.7105	1.0836	2.5967	1.0917	2.4928	21
40	1.0688	2.8334	1.0760	2.7085	1.0837	2.5949	1.0918	2.4912	20
41	1.0689	2.8312	1.0761	2.7065	1.0838	2.5931	1.0920	2.4895	19
42	1.0690	2.8290	1.0763	2.7045	1.0840	2.5913	1.0921	2.4879	18
43	1.0691	2.8269	1.0764	2.7026	1.0841	2.5895	1.0922	2.4862	17
44	1.0692	2.8247	1.0765	2.7006	1.0842	2.5877	1.0924	2.4846	16
45	1.0694	2.8225	1.0766	2.6986	1.0844	2.5859	1.0925	2.4829	15
46	1.0695	2.8204	1.0768	2.6967	1.0845	2.5841	1.0927	2.4813	14
47	1.0696	2.8182	1.0769	2.6947	1.0846	2.5823	1.0928	2.4797	13
48	1.0697	2.8160	1.0770	2.6927	1.0847	2.5805	1.0929	2.4780	12
49	1.0698	2.8139	1.0771	2.6908	1.0849	2.5787	1.0931	2.4764	11
50	1.0699	2.8117	1.0773	2.6888	1.0850	2.5770	1.0932	2.4748	10
51	1.0701	2.8096	1.0774	2.6869	1.0851	2.5752	1.0934	2.4731	9
52	1.0702	2.8074	1.0775	2.6849	1.0853	2.5734	1.0935	2.4715	8
53	1.0703	2.8053	1.0776	2.6830	1.0854	2.5716	1.0936	2.4699	7
54	1.0704	2.8032	1.0778	2.6810	1.0855	2.5699	1.0938	2.4683	6
55	1.0705	2.8010	1.0779	2.6791	1.0857	2.5681	1.0939	2.4666	5
56	1.0707	2.7989	1.0780	2.6772	1.0858	2.5663	1.0941	2.4650	4
57	1.0708	2.7968	1.0781	2.6752	1.0859	2.5646	1.0942	2.4634	3
58	1.0709	2.7947	1.0783	2.6733	1.0861	2.5628	1.0943	2.4618	2
59	1.0710	2.7925	1.0784	2.6714	1.0862	2.5610	1.0945	2.4602	1
60	1.0711	2.7904	1.0785	2.6695	1.0864	2.5593	1.0946	2.4586	0
′	Co-sec.	Sec.	Co-sec.	Sec.	Co-sec.	Sec.	Co-sec.	Sec.	′
	69°		68°		67°		66°		

′	24° Sec.	24° Co-sec.	25° Sec.	25° Co-sec.	26° Sec.	26° Co-sec.	27° Sec.	27° Co-sec.
0	1.0946	2.4586	1.1034	2.3662	1.1126	2.2812	1.1223	2.2027
1	1.0948	2.4570	1.1035	2.3647	1.1127	2.2798	1.1225	2.2014
2	1.0949	2.4554	1.1037	2.3632	1.1129	2.2784	1.1226	2.2002
3	1.0951	2.4538	1.1038	2.3618	1.1131	2.2771	1.1228	2.1989
4	1.0952	2.4522	1.1040	2.3603	1.1132	2.2757	1.1230	2.1977
5	1.0953	2.4506	1.1041	2.3588	1.1134	2.2744	1.1231	2.1964
6	1.0955	2.4490	1.1043	2.3574	1.1135	2.2730	1.1233	2.1952
7	1.0956	2.4474	1.1044	2.3559	1.1137	2.2717	1.1235	2.1939
8	1.0958	2.4458	1.1046	2.3544	1.1139	2.2703	1.1237	2.1927
9	1.0959	2.4442	1.1047	2.3530	1.1140	2.2690	1.1238	2.1914
10	1.0961	2.4426	1.1049	2.3515	1.1142	2.2676	1.1240	2.1902
11	1.0962	2.4411	1.1050	2.3501	1.1143	2.2663	1.1242	2.1889
12	1.0963	2.4395	1.1052	2.3486	1.1145	2.2650	1.1243	2.1877
13	1.0965	2.4379	1.1053	2.3472	1.1147	2.2636	1.1245	2.1865
14	1.0966	2.4363	1.1055	2.3457	1.1148	2 2623	1.1247	2.1852
15	1.0968	2.4347	1.1056	2.3443	1.1150	2.2610	1.1248	2.1840
16	1.0969	2.4332	1.1058	2.3428	1.1151	2.2596	1.1250	2.1828
17	1.0971	2.4316	1.1059	2.3414	1.1153	2.2583	1.1252	2.1815
18	1.0972	2.4300	1.1061	2.3399	1.1155	2.2570	1.1253	2.1803
19	1.0973	2.4285	1.1062	2.3385	1.1156	2.2556	1.1255	2.1791
20	1.0975	2.4269	1.1064	2.3371	1.1158	2.2543	1.1257	2.1778
21	1.0976	2.4254	1.1065	2.3356	1.1159	2.2530	1.1258	2.1766
22	1.0978	2.4238	1.1067	2.3342	1.1161	2.2517	1.1260	2.1754
23	1.0979	2.4222	1.1068	2.3328	1.1163	2.2503	1.1262	2.1742
24	1.0981	2.4207	1.1070	2.3313	1.1164	2.2490	1.1264	2.1730
25	1.0982	2.4191	1.1072	2.3299	1.1166	2.2477	1.1265	2.1717
26	1.0984	2.4176	1.1073	2.3285	1.1167	2.2464	1.1267	2.1705
27	1.0985	2.4160	1.1075	2.3271	1.1169	2.2451	1.1269	2.1693
28	1.0986	2.4145	1.1076	2.3256	1.1171	2.2438	1.1270	2.1681
29	1.0988	2.4130	1.1078	2.3242	1.1172	2.2425	1.1272	2.1669
30	1.0989	2.4114	1.1079	2.3228	1.1174	2.2411	1.1274	2.1657
31	1.0991	2.4099	1.1081	2.3214	1.1176	2.2398	1.1275	2.1645
32	1.0992	2.4083	1.1082	2.3200	1.1177	2.2385	1.1277	2.1633
33	1.0994	2.4068	1.1084	2.3186	1.1179	2.2372	1.1279	2.1620
34	1.0995	2.4053	1.1085	2.3172	1.1180	2.2359	1.1281	2.1608
35	1.0997	2.4037	1.1087	2.3158	1.1182	2.2346	1.1282	2.1596
36	1.0998	2.4022	1.1088	2.3143	1.1184	2.2333	1.1284	2.1584
37	1.1000	2.4007	1.1090	2.3129	1.1185	2.2320	1.1286	2.1572
38	1.1001	2.3992	1.1092	2.3115	1.1187	2.2307	1.1287	2.1560
39	1.1003	2.3976	1.1093	2.3101	1.1189	2.2294	1.1289	2.1548
40	1.1004	2.3961	1.1095	2.3087	1.1190	2.2282	1.1291	2.1536
41	1.1005	2.3946	1.1096	2.3073	1.1192	2.2269	1.1293	2.1525
42	1.1007	2.3931	1.1098	2.3059	1.1193	2.2256	1.1294	2.1513
43	1.1008	2.3916	1.1099	2.3046	1.1195	2.2243	1.1296	2.1501
44	1.1010	2.3901	1.1101	2.3032	1.1197	2.2230	1.1298	2.1489
45	1.1011	2.3886	1.1102	2.3018	1.1198	2.2217	1.1299	2.1477
46	1.1013	2.3871	1.1104	2.3004	1.1200	2.2204	1.1301	2.1465
47	1.1014	2.3856	1.1106	2.2990	1.1202	2.2192	1.1303	2.1453
48	1.1016	2.3841	1.1107	2.2976	1.1203	2.2179	1.1305	2.1441
49	1.1017	2.3826	1.1109	2.2962	1.1205	2.2166	1.1306	2.1430
50	1.1019	2.3811	1.1110	2.2949	1.1207	2.2153	1.1308	2.1418
51	1.1020	2.3796	1.1112	2.2935	1.1208	2.2141	1.1310	2.1406
52	1.1022	2.3781	1.1113	2.2921	1.1210	2.2128	1.1312	2.1394
53	1.1023	2.3766	1.1115	2.2907	1.1212	2.2115	1.1313	2.1382
54	1.1025	2.3751	1.1116	2.2894	1.1213	2.2103	1.1315	2.1371
55	1.1026	2.3736	1.1118	2.2880	1.1215	2.2090	1.1317	2.1359
56	1.1028	2.3721	1.1120	2.2866	1.1217	2.2077	1.1319	2.1347
57	1.1029	2.3706	1.1121	2.2853	1.1218	2.2065	1.1320	2.1335
58	1.1031	2.3691	1.1123	2.2839	1.1220	2.2052	1.1322	2.1324
59	1.1032	2.3677	1.1124	2.2825	1.1222	2.2039	1.1324	2.1317
60	1.1034	2.3662	1.1126	2.2812	1.1223	2.2027	1.1326	2.1300
′	Co-sec.	Sec.	Co-sec.	Sec.	Co-sec.	Sec.	Co-sec.	Sec.
	65°		64°		63°		62°	

′	28° Sec.	28° Co-sec.	29° Sec.	29° Co-sec.	30° Sec.	30° Co-sec.	31° Sec.	31° Co-sec.	′
0	1.1326	2.1300	1.1433	2.0627	1.1547	2.0000	1.1666	1.9416	60
1	1.1327	2.1289	1.1435	2.0616	1.1549	1.9990	1.1668	1.9407	59
2	1.1329	2.1277	1.1437	2.0605	1.1551	1.9980	1.1670	1.9397	58
3	1.1331	2.1266	1.1439	2.0594	1.1553	1.9970	1.1672	1.9388	57
4	1.1333	2.1254	1.1441	2.0583	1.1555	1.9960	1.1674	1.9378	56
5	1.1334	2.1242	1.1443	2.0573	1.1557	1.9950	1.1676	1.9369	55
6	1.1336	2.1231	1.1445	2.0562	1.1559	1.9940	1.1678	1.9360	54
7	1.1338	2.1219	1.1446	2.0551	1.1561	1.9930	1.1681	1.9350	53
8	1.1340	2.1208	1.1448	2.0540	1.1562	1.9920	1.1683	1.9341	52
9	1.1341	2.1196	1.1450	2.0530	1.1564	1.9910	1.1685	1.9332	51
10	1.1343	2.1185	1.1452	2.0519	1.1566	1.9900	1.1687	1.9322	50
11	1.1345	2.1173	1.1454	2.0508	1.1568	1.9890	1.1689	1.9313	49
12	1.1347	2.1162	1.1456	2.0498	1.1570	1.9880	1.1691	1.9304	48
13	1.1349	2.1150	1.1458	2.0487	1.1572	1.9870	1.1693	1.9295	47
14	1.1350	2.1139	1.1459	2.0476	1.1574	1.9860	1.1695	1.9285	46
15	1.1352	2.1127	1.1461	2.0466	1.1576	1.9850	1.1697	1.9276	45
16	1.1354	2.1116	1.1463	2.0455	1.1578	1.9840	1.1699	1.9267	44
17	1.1356	2.1104	1.1465	2.0444	1.1580	1.9830	1.1701	1.9258	43
18	1.1357	2.1093	1.1467	2.0434	1.1582	1.9820	1.1703	1.9248	42
19	1.1359	2.1082	1.1469	2.0423	1.1584	1.9811	1.1705	1.9239	41
20	1.1361	2.1070	1.1471	2.0413	1.1586	1.9801	1.1707	1.9230	40
21	1.1363	2.1059	1.1473	2.0402	1.1588	1.9791	1.1709	1.9221	39
22	1.1365	2.1048	1.1474	2.0392	1.1590	1.9781	1.1712	1.9212	38
23	1.1366	2.1036	1.1476	2.0381	1.1592	1.9771	1.1714	1.9203	37
24	1.1368	2.1025	1.1478	2.0370	1.1594	1.9761	1.1716	1.9193	36
25	1.1370	2.1014	1.1480	2.0360	1.1596	1.9752	1.1718	1.9184	35
26	1.1372	2.1002	1.1482	2.0349	1.1598	1.9742	1.1720	1.9175	34
27	1.1373	2.0991	1.1484	2.0339	1.1600	1.9732	1.1722	1.9166	33
28	1.1375	2.0980	1.1486	2.0329	1.1602	1.9722	1.1724	1.9157	32
29	1.1377	2.0969	1.1488	2.0318	1.1604	1.9713	1.1726	1.9148	31
30	1.1379	2.0957	1.1489	2.0308	1.1606	1.9703	1.1728	1.9139	30
31	1.1381	2.0946	1.1491	2.0297	1.1608	1.9693	1.1730	1.9130	29
32	1.1382	2.0935	1.1493	2.0287	1.1610	1.9683	1.1732	1.9121	28
33	1.1384	2.0924	1.1495	2.0276	1.1612	1.9674	1.1734	1.9112	27
34	1.1386	2.0912	1.1497	2.0266	1.1614	1.9664	1.1737	1.9102	26
35	1.1388	2.0901	1.1499	2.0256	1.1616	1.9654	1.1739	1.9093	25
36	1.1390	2.0890	1.1501	2.0245	1.1618	1.9645	1.1741	1.9084	24
37	1.1391	2.0879	1.1503	2.0235	1.1620	1.9635	1.1743	1.9075	23
38	1.1393	2.0868	1.1505	2.0224	1.1622	1.9625	1.1745	1.9066	22
39	1.1395	2.0857	1.1507	2.0214	1.1624	1.9616	1.1747	1.9057	21
40	1.1397	2.0846	1.1508	2.0204	1.1626	1.9606	1.1749	1.9048	20
41	1.1399	2.0835	1.1510	2.0194	1.1628	1.9596	1.1751	1.9039	19
42	1.1401	2.0824	1.1512	2.0183	1.1630	1.9587	1.1753	1.9030	18
43	1.1402	2.0812	1.1514	2.0173	1.1632	1.9577	1.1756	1.9021	17
44	1.1404	2.0801	1.1516	2.0163	1.1634	1.9568	1.1758	1.9013	16
45	1.1406	2.0790	1.1518	2.0152	1.1636	1.9558	1.1760	1.9004	15
46	1.1408	2.0779	1.1520	2.0142	1.1638	1.9549	1.1762	1.8995	14
47	1.1410	2.0768	1.1522	2.0132	1.1640	1.9539	1.1764	1.8986	13
48	1.1411	2.0757	1.1524	2.0122	1.1642	1.9530	1.1766	1.8977	12
49	1.1413	2.0746	1.1526	2.0111	1.1644	1.9520	1.1768	1.8968	11
50	1.1415	2.0735	1.1528	2.0101	1.1646	1.9510	1.1770	1.8959	10
51	1.1417	2.0725	1.1530	2.0091	1.1648	1.9501	1.1772	1.8950	9
52	1.1419	2.0714	1.1531	2.0081	1.1650	1.9491	1.1775	1.8941	8
53	1.1421	2.0703	1.1533	2.0071	1.1652	1.9482	1.1777	1.8932	7
54	1.1422	2.0692	1.1535	2.0061	1.1654	1.9473	1.1779	1.8924	6
55	1.1424	2.0681	1.1537	2.0050	1.1656	1.9463	1.1781	1.8915	5
56	1.1426	2.0670	1.1539	2.0040	1.1658	1.9454	1.1783	1.8906	4
57	1.1428	2.0659	1.1541	2.0030	1.1660	1.9444	1.1785	1.8897	3
58	1.1430	2.0648	1.1543	2.0020	1.1662	1.9435	1.1787	1.8888	2
59	1.1432	2.0637	1.1545	2.0010	1.1664	1.9425	1.1790	1.8879	1
60	1.1433	2.0627	1.1547	2.0000	1.1666	1.9416	1.1792	1.8871	0
′	61° Co-sec.	61° Sec.	60° Co-sec.	60° Sec.	59° Co-sec.	59° Sec.	58° Co-sec.	58° Sec.	′

	32°		33°		34°		35°	
′	Sec.	Co-sec.	Sec.	Co-sec.	Sec.	Co-sec.	Sec.	Co-sec.
0	1.1792	1.8871	1.1924	1.8361	1.2062	1.7883	1.2208	1.7434
1	1.1794	1.8862	1.1926	1.8352	1.2064	1.7875	1.2210	1.7427
2	1.1796	1.8853	1.1928	1.8344	1.2067	1.7867	1.2213	1.7420
3	1.1798	1.8844	1.1930	1.8336	1.2069	1.7860	1.2215	1.7413
4	1.1800	1.8836	1.1933	1.8328	1.2072	1.7852	1.2218	1.7405
5	1.1802	1.8827	1.1935	1.8320	1.2074	1.7844	1.2220	1.7398
6	1.1805	1.8818	1.1937	1.8311	1.2076	1.7837	1.2223	1.7391
7	1.1807	1.8809	1.1939	1.8303	1.2079	1.7829	1.2225	1.7384
8	1.1809	1.8801	1.1942	1.8295	1.2081	1.7821	1.2228	1.7377
9	1.1811	1.8792	1.1944	1.8287	1.2083	1.7814	1.2230	1.7369
10	1.1813	1.8783	1.1946	1.8279	1.2086	1.7806	1.2233	1.7362
11	1.1815	1.8785	1.1948	1.8271	1.2088	1.7798	1.2235	1.7355
12	1.1818	1.8766	1.1951	1.8263	1.2091	1.7791	1.2238	1.7348
13	1.1820	1.8757	1.1953	1.8255	1.2093	1.7783	1.2240	1.7341
14	1.1822	1.8749	1.1955	1.8246	1.2095	1.7776	1.2243	1.7334
15	1.1824	1.8740	1.1958	1.8238	1.2098	1.7768	1.2245	1.7327
16	1.1826	1.8731	1.1960	1.8230	1.2100	1.7760	1.2248	1.7319
17	1.1828	1.8723	1.1962	1.8222	1.2103	1.7753	1.2250	1.7312
18	1.1831	1.8714	1.1964	1.8214	1.2105	1.7745	1.2253	1.7305
19	1.1833	1.8706	1.1967	1.8206	1.2107	1.7738	1.2255	1.7298
20	1.1835	1.8697	1.1969	1.8198	1.2110	1.7730	1.2258	1.7291
21	1.1837	1.8688	1.1971	1.8190	1.2112	1.7723	1.2260	1.7284
22	1.1839	1.8680	1.1974	1.8182	1.2115	1.7715	1.2263	1.7277
23	1.1841	1.8671	1.1976	1.8174	1.2117	1.7708	1.2265	1.7270
24	1.1844	1.8663	1.1978	1.8166	1.2119	1.7700	1.2268	1.7263
25	1.1846	1.8654	1.1980	1.8158	1.2122	1.7693	1.2270	1.7256
26	1.1848	1.8646	1.1983	1.8150	1.2124	1.7685	1.2273	1.7249
27	1.1850	1.8637	1.1985	1.8142	1.2127	1.7678	1.2276	1.7242
28	1.1852	1.8629	1.1987	1.8134	1.2129	1.7670	1.2278	1.7234
29	1.1855	1.8620	1.1990	1.8126	1.2132	1.7663	1.2281	1.7227
30	1.1857	1.8611	1.1992	1.8118	1.2134	1.7655	1.2283	1.7220
31	1.1859	1.8603	1.1994	1.8110	1.2136	1.7648	1.2286	1.7213
32	1.1861	1.8595	1.1997	1.8102	1.2139	1.7640	1.2288	1.7206
33	1.1863	1.8586	1.1999	1.8094	1.2141	1.7633	1.2291	1.7199
34	1.1866	1.8578	1.2001	1.8086	1.2144	1.7625	1.2293	1.7192
35	1.1868	1.8569	1.2004	1.8078	1.2146	1.7618	1.2296	1.7185
36	1.1870	1.8561	1.2006	1.8070	1.2149	1.7610	1.2298	1.7178
37	1.1872	1.8552	1.2008	1.8062	1.2151	1.7603	1.2301	1.7171
38	1.1874	1.8544	1.2010	1.8054	1.2153	1.7596	1.2304	1.7164
39	1.1877	1.8535	1.2013	1.8047	1.2156	1.7588	1.2306	1.7157
40	1.1879	1.8527	1.2015	1.8039	1.2158	1.7581	1.2309	1.7151
41	1.1881	1.8519	1.2017	1.8031	1.2161	1.7573	1.2311	1.7144
42	1.1883	1.8510	1.2020	1.8023	1.2163	1.7566	1.2314	1.7137
43	1.1886	1.8502	1.2022	1.8015	1.2166	1.7559	1.2316	1.7130
44	1.1888	1.8493	1.2024	1.8007	1.2168	1.7551	1.2319	1.7123
45	1.1890	1.8485	1.2027	1.7999	1.2171	1.7544	1.2322	1.7116
46	1.1892	1.8477	1.2029	1.7992	1.2173	1.7537	1.2324	1.7109
47	1.1894	1.8468	1.2031	1.7984	1.2175	1.7529	1.2327	1.7102
48	1.1897	1.8460	1.2034	1.7976	1.2178	1.7522	1.2329	1.7095
49	1.1899	1.8452	1.2036	1.7968	1.2180	1.7514	1.2332	1.7088
50	1.1901	1.8443	1.2039	1.7960	1.2183	1.7507	1.2335	1.7081
51	1.1903	1.8435	1.2041	1.7953	1.2185	1.7500	1.2337	1.7075
52	1.1906	1.8427	1.2043	1.7945	1.2188	1.7493	1.2340	1.7068
53	1.1908	1.8418	1.2046	1.7937	1.2190	1.7485	1.2342	1.7061
54	1.1910	1.8410	1.2048	1.7929	1.2193	1.7478	1.2345	1.7054
55	1.1912	1.8402	1.2050	1.7921	1.2195	1.7471	1.2348	1.7047
56	1.1915	1.8394	1.2053	1.7914	1.2198	1.7463	1.2350	1.7040
57	1.1917	1.8385	1.2055	1.7906	1.2200	1.7456	1.2353	1.7033
58	1.1919	1.8377	1.2057	1.7898	1.2203	1.7449	1.2355	1.7027
59	1.1921	1.8369	1.2060	1.7891	1.2205	1.7442	1.2358	1.7020
60	1.1922	1.8361	1.2062	1.7883	1.2208	1.7434	1.2361	1.7013
′	Co-sec.	Sec.	Co-sec.	Sec.	Co-sec.	Sec.	Co-sec.	Sec.
	57°		56°		55°		54°	

′	36° Sec.	36° Co-sec.	37° Sec.	37° Co-sec.	38° Sec.	38° Co-sec.	39° Sec.	39° Co-sec.	′
0	1.2361	1.7013	1.2521	1.6616	1.2690	1.6243	1.2867	1.5890	60
1	1.2363	1.7006	1.2524	1.6610	1.2693	1.6237	1.2871	1.5884	59
2	1.2366	1.6999	1.2527	1.6603	1.2696	1.6231	1.2874	1.5879	58
3	1.2368	1.6993	1.2530	1.6597	1.2699	1.6224	1.2877	1.5873	57
4	1.2371	1.6986	1.2532	1.6591	1.2702	1.6218	1.2880	1.5867	56
5	1.2374	1.6979	1.2535	1.6584	1.2705	1.6212	1.2883	1.5862	55
6	1.2376	1.6972	1.2538	1.6578	1.2707	1.6206	1.2886	1.5856	54
7	1.2379	1.6965	1.2541	1.6572	1.2710	1.6200	1.2889	1.5850	53
8	1.2382	1.6959	1.2543	1.6565	1.2713	1.6194	1.2892	1.5845	52
9	1.2384	1.6952	1.2546	1.6559	1.2716	1.6188	1.2895	1.5839	51
10	1.2387	1.6945	1.2549	1.6552	1.2719	1.6182	1.2898	1.5833	50
11	1.2389	1.6938	1.2552	1.6546	1.2722	1.6176	1.2901	1.5828	49
12	1.2392	1.6932	1.2554	1.6540	1.2725	1.6170	1.2904	1.5822	48
13	1.2395	1.6925	1.2557	1.6533	1.2728	1.6164	1.2907	1.5816	47
14	1.2397	1.6918	1.2560	1.6527	1.2731	1.6159	1.2910	1.5811	46
15	1.2400	1.6912	1.2563	1.6521	1.2734	1.6153	1.2913	1.5805	45
16	1.2403	1.6905	1.2565	1.6514	1.2737	1.6147	1.2916	1.5799	44
17	1.2405	1.6898	1.2568	1.6508	1.2739	1.6141	1.2919	1.5794	43
18	1.2408	1.6891	1.2571	1.6502	1.2742	1.6135	1.2922	1.5788	42
19	1.2411	1.6885	1.2574	1.6496	1.2745	1.6129	1.2926	1.5783	41
20	1.2413	1.6878	1.2577	1.6489	1.2748	1.6123	1.2929	1.5777	40
21	1.2416	1.6871	1.2579	1.6483	1.2751	1.6117	1.2932	1.5771	39
22	1.2419	1.6865	1.2582	1.6477	1.2754	1.6111	1.2935	1.5766	38
23	1.2421	1.6858	1.2585	1.6470	1.2757	1.6105	1.2938	1.5760	37
24	1.2424	1.6851	1.2588	1.6464	1.2760	1.6099	1.2941	1.5755	36
25	1.2427	1.6845	1.2591	1.6458	1.2763	1.6093	1.2944	1.5749	35
26	1.2429	1.6838	1.2593	1.6452	1.2766	1.6087	1.2947	1.5743	34
27	1.2432	1.6831	1.2596	1.6445	1.2769	1.6081	1.2950	1.5738	33
28	1.2435	1.6825	1.2599	1.6439	1.2772	1.6077	1.2953	1.5732	32
29	1.2437	1.6818	1.2602	1.6433	1.2775	1.6070	1.2956	1.5727	31
30	1.2440	1.6812	1.2605	1.6427	1.2778	1.6064	1.2960	1.5721	30
31	1.2443	1.6805	1.2607	1.6420	1.2781	1.6058	1.2963	1.5716	29
32	1.2445	1.6798	1.2610	1.6414	1.2784	1.6052	1.2966	1.5710	28
33	1.2448	1.6792	1.2613	1.6408	1.2787	1.6046	1.2969	1.5705	27
34	1.2451	1.6785	1.2616	1.6402	1.2790	1.6040	1.2972	1.5699	26
35	1.2453	1.6779	1.2619	1.6396	1.2793	1.6034	1.2975	1.5694	25
36	1.2456	1.6772	1.2622	1.6389	1.2795	1.6029	1.2978	1.5688	24
37	1.2459	1.6766	1.2624	1.6383	1.2798	1.6023	1.2981	1.5683	23
38	1.2461	1.6759	1.2627	1.6377	1.2801	1.6017	1.2985	1.5677	22
39	1.2464	1.6752	1.2630	1.6371	1.2804	1.6011	1.2988	1.5672	21
40	1.2467	1.6746	1.2633	1.6365	1.2807	1.6005	1.2991	1.5666	20
41	1.2470	1.6739	1.2636	1.6359	1.2810	1.6000	1.2994	1.5661	19
42	1.2472	1.6733	1.2639	1.6352	1.2813	1.5994	1.2997	1.5655	18
43	1.2475	1.6726	1.2641	1.6346	1.2816	1.5988	1.3000	1.5650	17
44	1.2478	1.6720	1.2644	1.6340	1.2819	1.5982	1.3003	1.5644	16
45	1.2480	1.6713	1.2647	1.6334	1.2822	1.5976	1.3006	1.5639	15
46	1.2483	1.6707	1.2650	1.6328	1.2825	1.5971	1.3010	1.5633	14
47	1.2486	1.6700	1.2653	1.6322	1.2828	1.5965	1.3013	1.5628	13
48	1.2488	1.6694	1.2656	1.6316	1.2831	1.5959	1.3016	1.5622	12
49	1.2490	1.6687	1.2659	1.6309	1.2834	1.5953	1.3019	1.5617	11
50	1.2494	1.6681	1.2661	1.6303	1.2837	1.5947	1.3022	1.5611	10
51	1.2497	1.6674	1.2664	1.6297	1.2840	1.5942	1.3025	1.5606	9
52	1.2499	1.6668	1.2667	1.6291	1.2843	1.5936	1.3029	1.5600	8
53	1.2502	1.6661	1.2670	1.6285	1.2846	1.5930	1.3032	1.5595	7
54	1.2505	1.6655	1.2673	1.6279	1.2849	1.5924	1.3035	1.5590	6
55	1.2508	1.6648	1.2676	1.6273	1.2852	1.5919	1.3038	1.5584	5
56	1.2510	1.6642	1.2679	1.6267	1.2855	1.5913	1.3041	1.5579	4
57	1.2513	1.6636	1.2681	1.6261	1.2858	1.5907	1.3044	1.5573	3
58	1.2516	1.6629	1.2684	1.6255	1.2861	1.5901	1.3048	1.5568	2
59	1.2519	1.6623	1.2687	1.6249	1.2864	1.5896	1.3051	1.5563	1
60	1.2521	1.6616	1.2690	1.6243	1.2867	1.5890	1.3054	1.5557	0
′	Co-sec.	Sec.	Co-sec.	Sec.	Co-sec.	Sec.	Co-sec.	Sec.	′
	53°		52°		51°		50°		

′	40°		41°		42°		43°		′
	Sec.	Co-sec.	Sec.	Co-sec.	Sec.	Co-sec.	Sec.	Co-sec.	
0	1.3054	1.5557	1.3250	1.5242	1.3456	1.4945	1.3673	1.4663	6
1	1.3057	1.5552	1.3253	1.5237	1.3460	1.4940	1.3677	1.4658	5
2	1.3060	1.5546	1.3257	1.5232	1.3463	1.4935	1.3681	1.4654	5
3	1.3064	1.5541	1.3260	1.5227	1.3467	1.4930	1.3684	1.4649	5
4	1.3067	1.5536	1.3263	1.5222	1.3470	1.4925	1.3688	1.4644	5
5	1.3070	1.5530	1.3267	1.5217	1.3474	1.4921	1.3692	1.4640	5
6	1.3073	1.5525	1.3270	1.5212	1.3477	1.4916	1.3695	1.4635	5
7	1.3076	1.5520	1.3274	1.5207	1.3481	1.4911	1.3699	1.4631	5
8	1.3080	1.5514	1.3277	1.5202	1.3485	1.4906	1.3703	1.4626	5
9	1.3083	1.5509	1.3280	1.5197	1.3488	1.4901	1.3707	1.4622	5
10	1.3086	1.5503	1.3284	1.5192	1.3492	1.4897	1.3710	1.4617	5
11	1.3089	1.5498	1.3287	1.5187	1.3495	1.4892	1.3714	1.4613	4
12	1.3092	1.5493	1.3290	1.5182	1.3499	1.4887	1.3718	1.4608	4
13	1.3096	1.5487	1.3294	1.5177	1.3502	1.4882	1.3722	1.4604	4
14	1.3099	1.5482	1.3297	1.5171	1.3506	1.4877	1.3725	1.4599	4
15	1.3102	1.5477	1.3301	1.5166	1.3509	1.4873	1.3729	1.4595	4
16	1.3105	1.5471	1.3304	1.5161	1.3513	1.4868	1.3733	1.4590	4
17	1.3109	1.5466	1.3307	1.5156	1.3517	1.4863	1.3737	1.4586	4
18	1.3112	1.5461	1.3311	1.5151	1.3520	1.4858	1.3740	1.4581	4
19	1.3115	1.5456	1.3314	1.5146	1.3524	1.4854	1.3744	1.4577	4
20	1.3118	1.5450	1.3318	1.5141	1.3527	1.4849	1.3748	1.4572	4
21	1.3121	1.5445	1.3321	1.5136	1.3531	1.4844	1.3752	1.4568	3
22	1.3125	1.5440	1.3324	1.5131	1.3534	1.4839	1.3756	1.4563	3
23	1.3128	1.5434	1.3328	1.5126	1.3538	1.4835	1.3759	1.4559	3
24	1.3131	1.5429	1.3331	1.5121	1.3542	1.4830	1.3763	1.4554	3
25	1.3134	1.5424	1.3335	1.5116	1.3545	1.4825	1.3767	1.4550	3
26	1.3138	1.5419	1.3338	1.5111	1.3549	1.4821	1.3771	1.4545	3
27	1.3141	1.5413	1.3342	1.5106	1.3552	1.4816	1.3774	1.4541	3
28	1.3144	1.5408	1.3345	1.5101	1.3556	1.4811	1.3778	1.4536	3
29	1.3148	1.5403	1.3348	1.5096	1.3560	1.4806	1.3782	1.4532	3
30	1.3151	1.5398	1.3352	1.5092	1.3563	1.4802	1.3786	1.4527	3
31	1.3154	1.5392	1.3355	1.5087	1.3567	1.4797	1.3790	1.4523	2
32	1.3157	1.5387	1.3359	1.5082	1.3571	1.4792	1.3794	1.4518	2
33	1.3161	1.5382	1.3362	1.5077	1.3574	1.4788	1.3797	1.4514	2
34	1.3164	1.5377	1.3366	1.5072	1.3578	1.4783	1.3801	1.4510	2
35	1.3167	1.5371	1.3369	1.5067	1.3581	1.4778	1.3805	1.4505	2
36	1.3170	1.5366	1.3372	1.5062	1.3585	1.4774	1.3809	1.4501	2
37	1.3174	1.5361	1.3376	1.5057	1.3589	1.4769	1.3813	1.4496	2
38	1.3177	1.5356	1.3379	1.5052	1.3592	1.4764	1.3816	1.4492	2
39	1.3180	1.5351	1.3383	1.5047	1.3596	1.4760	1.3820	1.4487	2
40	1.3184	1.5345	1.3386	1.5042	1.3600	1.4755	1.3824	1.4483	2
41	1.3187	1.5340	1.3390	1.5037	1.3603	1.4750	1.3828	1.4479	1
42	1.3190	1.5335	1.3393	1.5032	1.3607	1.4746	1.3832	1.4474	1
43	1.3193	1.5330	1.3397	1.5027	1.3611	1.4741	1.3836	1.4470	1
44	1.3197	1.5325	1.3400	1.5022	1.3614	1.4736	1.3839	1.4465	1
45	1.3200	1.5319	1.3404	1.5018	1.3618	1.4732	1.3843	1.4461	1
46	1.3203	1.5314	1.3407	1.5013	1.3622	1.4727	1.3847	1.4457	1
47	1.3207	1.5309	1.3411	1.5008	1.3625	1.4723	1.3851	1.4452	1
48	1.3210	1.5304	1.3414	1.5003	1.3629	1.4718	1.3855	1.4448	1
49	1.3213	1.5299	1.3418	1.4998	1.3633	1.4713	1.3859	1.4443	1
50	1.3217	1.5294	1.3421	1.4993	1.3636	1.4709	1.3863	1.4439	1
51	1.3220	1.5289	1.3425	1.4988	1.3640	1.4704	1.3867	1.4435	
52	1.3223	1.5283	1.3428	1.4983	1.3644	1.4699	1.3870	1.4430	
53	1.3227	1.5278	1.3432	1.4979	1.3647	1.4695	1.3874	1.4426	
54	1.3230	1.5273	1.3435	1.4974	1.3651	1.4690	1.3878	1.4422	
55	1.3233	1.5268	1.3439	1.4969	1.3655	1.4686	1.3882	1.4417	
56	1.3237	1.5263	1.3442	1.4964	1.3658	1.4681	1.3886	1.4413	
57	1.3240	1.5258	1.3446	1.4959	1.3662	1.4676	1.3890	1.4408	
58	1.3243	1.5253	1.3449	1.4954	1.3666	1.4672	1.3894	1.4404	
59	1.3247	1.5248	1.3453	1.4949	1.3669	1.4667	1.3898	1.4400	
60	1.3250	1.5242	1.3456	1.4945	1.3673	1.4663	1.3902	1.4395	
′	Co-sec.	Sec.	Co-sec.	Sec.	Co-sec.	Sec.	Co-sec.	Sec.	′
	49°		48°		47°		46°		

	44°				44°				44°		
′	Sec.	Co-sec.	′	′	Sec.	Co-sec.	′	′	Sec	Co-sec.	′
0	1.3902	1.4395	60	21	1.3984	1.4305	39	41	1.4065	1.4221	19
1	1.3905	1.4391	59	22	1.3988	1.4301	38	42	1.4069	1.4217	18
2	1.3909	1.4387	58	23	1.3992	1.4297	37	43	1.4073	1.4212	17
3	1.3913	1.4382	57	24	1.3996	1.4292	36	44	1 4077	1.4208	16
4	1.3917	1.4378	56	25	1.4000	1.4288	35	45	1.4081	1.4204	15
5	1.3921	1.4374	55	26	1.4004	1.4284	34	46	1.4085	1.4200	14
6	1.3925	1.4370	54	27	1.4008	1.4280	33	47	1.4089	1.4196	13
7	1.3929	1.4365	53	28	1.4012	1.4276	32	48	1.4093	1.4192	12
8	1.3933	1.4361	52	29	1.4016	1.4271	31	49	1.4097	1.4188	11
9	1.3937	1.4357	51	30	1.4020	1.4267	30	50	1.4101	1.4183	10
10	1.3941	1.4352	50	31	1.4024	1.4263	29	51	1.4105	1.4179	9
11	1.3945	1.4348	49	32	1.4028	1.4259	28	52	1.4109	1.4175	8
12	1.3949	1.4344	48	33	1.4032	1.4254	27	53	1.4113	1.4171	7
13	1.3953	1.4339	47	34	1.4036	1.4250	26	54	1.4117	1.4167	6
14	1.3957	1.4335	46	35	1.4040	1.4246	25	55	1.4122	1.4163	5
15	1.3960	1.4331	45	36	1.4044	1.4242	24	56	1.4126	1.4159	4
16	1.3964	1.4327	44	37	1.4048	1.4238	23	57	1.4130	1.4154	3
17	1.3968	1.4322	43	38	1.4052	1.4233	22	58	1.4134	1.4150	2
18	1.3972	1.4318	42	39	1.4056	1.4229	21	59	1.4138	1.4146	1
19	1.3976	1.4314	41	40	1.4060	1.4225	20	60	1.4142	1.4142	0
20	1.3980	1.4310	40								
	Co-sec.	Sec.	′	′	Co-sec.	Sec.	′	′	Co-sec.	Sec.	′
	45°				45°				45°		

Table of Logarithmic Numbers

N.	0	1	2	3	4	5	6	7	8	9	Diff.
100	000000	0434	0868	1301	1734	2166	2598	3029	3461	3891	43
101	4321	4751	5181	5609	6038	6466	6894	7321	7748	8174	42
102	8600	9026	9451	9876	*0300	*0724	*1147	*1570	*1993	*2415	42
103	012837	3259	3680	4100	4521	4940	5360	5779	6197	6616	42
104	7033	7451	7868	8284	8700	9116	9532	9947	*0361	*0775	41
105	021189	1603	2016	2428	2841	3252	3664	4075	4486	4896	41
106	5306	5715	6125	6533	6942	7350	7757	8164	8571	8978	40
107	9384	9789	*0195	*0600	*1004	*1408	*1812	*2216	*2619	*3021	40
108	033424	3826	4227	4628	5029	5430	5830	6230	6629	7028	40
109	7426	7825	8223	8620	9017	9414	9811	*0207	*0602	*0998	39

N.	Diff.	1	2	3	4	5	6	7	8	9	Di
PROPORTIONAL PARTS	434	43	87	130	174	217	260	304	347	391	4
	433	43	87	130	173	217	260	303	346	390	4
	432	43	86	130	173	216	259	302	346	389	4
	431	43	86	129	172	216	259	302	345	388	4
	430	43	86	129	172	215	258	301	344	387	4
	429	43	86	129	172	215	257	300	343	386	4
	428	43	86	128	171	214	257	300	342	385	4
	427	43	85	128	171	214	256	299	342	384	4
	426	43	85	128	170	213	256	298	341	383	4
	425	43	85	128	170	213	255	298	340	383	4
	424	42	85	127	170	212	254	297	339	382	4
	423	42	85	127	169	212	254	296	338	381	4
	422	42	84	127	169	211	253	295	338	380	4
	421	42	84	126	168	211	253	295	337	379	4
	420	42	84	126	168	210	252	294	336	378	4
	419	42	84	126	168	210	251	293	335	377	4
	418	42	84	125	167	209	251	293	334	376	4
	417	42	83	125	167	209	250	292	334	375	4
	416	42	83	125	166	208	250	291	333	374	4
	415	42	83	125	166	208	249	291	332	374	4
	414	41	83	124	166	207	248	290	331	373	4
	413	41	83	124	165	207	248	289	330	372	4
	412	41	82	124	165	206	247	288	330	371	4
	411	41	82	123	164	206	247	288	329	370	4
	410	41	82	123	164	205	246	287	328	369	4
	409	41	82	123	164	205	245	286	327	368	4
	408	41	82	122	163	204	245	286	326	367	4
	407	41	81	122	163	204	244	285	326	366	4
	406	41	81	122	162	203	244	284	325	365	4
	405	41	81	122	162	203	243	284	324	365	4
	404	40	81	121	162	202	242	283	323	364	4
	403	40	81	121	161	202	242	282	322	363	4
	402	40	80	121	161	201	241	281	322	362	4
	401	40	80	120	160	201	241	281	321	361	4
	400	40	80	120	160	200	240	280	320	360	4
	399	40	80	120	160	200	239	279	319	359	3
	398	40	80	119	159	199	239	279	318	358	3
	397	40	79	119	159	199	238	278	318	357	3
	396	40	79	119	158	198	238	277	317	356	3
	395	40	79	119	158	198	237	277	316	356	3
	394	39	79	118	158	197	236	276	315	355	3
	393	39	79	118	157	197	236	275	314	354	3
	392	39	78	118	157	196	235	274	314	353	3
	391	39	78	117	156	196	235	274	313	352	3
	390	39	78	117	156	195	234	273	312	351	3
	389	39	78	117	156	195	233	272	311	350	3
	388	39	78	116	155	194	233	272	310	349	3
	Diff.	1	2	3	4	5	6	7	8	9	D

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N.	0	1	2	3	4	5	6	7	8	9	Diff.
10	041393	1787	2182	2576	2969	3362	3755	4148	4540	4932	393
11	5323	5714	6105	6495	6885	7275	7664	8053	8442	8830	390
12	9218	9606	9993	*0380	*0766	*1153	*1538	*1924	*2309	*2694	386
13	053078	3463	3846	4230	4613	4996	5378	5760	6142	6524	383
14	6905	7286	7666	8046	8426	8805	9185	9563	9942	*0320	379
15	060698	1075	1452	1829	2206	2582	2958	3333	3709	4083	376
16	4458	4832	5206	5580	5953	6326	6699	7071	7443	7815	373
17	8186	8557	8928	9298	9668	*0038	*0407	*0776	*1145	*1514	370
18	071882	2250	2617	2985	3352	3718	4085	4451	4816	5182	366
19	5547	5912	6276	6640	7004	7368	7731	8094	8457	8819	363
20	079181	9543	9904	*0266	*0626	*0987	*1347	*1707	*2067	*2426	360
21	082785	3144	3503	3861	4219	4576	4934	5291	5647	6004	357
22	6360	6716	7071	7426	7781	8136	8490	8845	9198	9552	355
23	9905	*0258	*0611	*0963	*1315	*1667	*2018	*2370	*2721	*3071	352
24	093422	3772	4122	4471	4820	5169	5518	5866	6215	6562	349

N.	Diff.	1	2	3	4	5	6	7	8	9	Diff.
PROPORTIONAL PARTS	387	39	77	116	155	194	232	271	310	348	387
	386	39	77	116	154	193	232	270	309	347	386
	385	39	77	116	154	193	231	270	308	347	385
	384	38	77	115	154	192	230	269	307	346	384
	383	38	77	115	153	192	230	268	306	345	383
	382	38	76	115	153	191	229	267	306	344	382
	381	38	76	114	152	191	229	267	305	343	381
	380	38	76	114	152	190	228	266	304	342	380
	379	38	76	114	152	190	227	265	303	341	379
	378	38	76	113	151	189	227	265	302	340	378
	377	38	75	113	151	189	226	264	302	339	377
	376	38	75	113	150	188	226	263	301	338	376
	375	38	75	113	150	188	225	263	300	338	375
	374	37	75	112	150	187	224	262	299	337	374
	373	37	75	112	149	187	224	261	298	336	373
	372	37	74	112	149	186	223	260	298	335	372
	371	37	74	111	148	186	223	260	297	334	371
	370	37	74	111	148	185	222	259	296	333	370
	369	37	74	111	148	185	221	258	295	332	369
	368	37	74	110	147	184	221	258	294	331	368
	367	37	73	110	147	184	220	257	294	330	367
	366	37	73	110	146	183	220	256	293	329	366
	365	37	73	110	146	183	219	256	292	329	365
	364	36	73	109	146	182	218	255	291	328	364
	363	36	73	109	145	182	218	254	290	327	363
	362	36	72	109	145	181	217	253	290	326	362
	361	36	72	108	144	181	217	253	289	325	361
	360	36	72	108	144	180	216	252	288	324	360
	359	36	72	108	144	180	215	251	287	323	359
	358	36	72	107	143	179	215	251	286	322	358
	357	36	71	107	143	179	214	250	286	321	357
	356	36	71	107	142	178	214	249	285	320	356
	355	36	71	107	142	178	213	249	284	320	355
	354	35	71	106	142	177	212	248	283	319	354
	353	35	71	106	141	177	212	247	282	318	353
	352	35	70	106	141	176	211	246	282	317	352
	351	35	70	105	140	176	211	246	281	316	351
	350	35	70	105	140	175	210	245	280	315	350
	349	35	70	105	140	175	209	244	279	314	349
	348	35	70	104	139	174	209	244	278	313	348
	347	35	69	104	139	174	208	243	278	312	347
	Diff.	1	2	3	4	5	6	7	8	9	Diff.

N.	0	1	2	3	4	5	6	7	8	9	Di
125	096910	7257	7604	7951	8298	8644	8990	9335	9681	*0026	34
126	100371	0715	1059	1403	1747	2091	2434	2777	3119	3462	34
127	3804	4146	4487	4828	5169	5510	5851	6191	6531	6871	34
128	7210	7549	7888	8227	8565	8903	9241	9579	9916	*0253	33
129	110590	0926	1263	1599	1934	2270	2605	2940	3275	3609	33
130	113943	4277	4611	4944	5278	5611	5943	6276	6608	6940	33
131	7271	7603	7934	8265	8595	8926	9256	9586	9915	*0245	33
132	120574	0903	1231	1560	1888	2216	2544	2871	3198	3525	32
133	3852	4178	4504	4830	5156	5481	5806	6131	6456	6781	32
134	7105	7429	7753	8076	8399	8722	9045	9368	9690	*0012	32
135	130334	0655	0977	1298	1619	1939	2260	2580	2900	3219	32
136	3539	3858	4177	4496	4814	5133	5451	5769	6086	6403	31
137	6721	7037	7354	7671	7987	8303	8618	8934	9249	9564	31
138	9879	*0194	*0508	*0822	*1136	*1450	*1763	*2076	*2389	*2702	31
139	143015	3327	3639	3951	4263	4574	4885	5196	5507	5818	31

N.	Diff.	1	2	3	4	5	6	7	8	9	Di
PROPORTIONAL PARTS	347	35	69	104	139	174	208	243	278	312	34
	346	35	69	104	138	173	208	242	277	311	34
	345	35	69	104	138	173	207	242	276	311	34
	344	34	69	103	138	172	206	241	275	310	34
	343	34	69	103	137	172	206	240	274	309	34
	342	34	68	103	137	171	205	239	274	308	34
	341	34	68	102	136	171	205	239	273	307	34
	340	34	68	102	136	170	204	238	272	306	34
	339	34	68	102	136	170	203	237	271	305	33
	338	34	68	101	135	169	203	237	270	304	33
	337	34	67	101	135	169	202	236	270	303	33
	336	34	67	101	134	168	202	235	269	302	33
	335	34	67	101	134	168	201	235	268	302	33
	334	33	67	100	134	167	200	234	267	301	33
	333	33	67	100	133	167	200	233	266	300	33
	332	33	66	100	133	166	199	232	266	299	33
	331	33	66	99	132	166	199	232	265	298	33
	330	33	66	99	132	165	198	231	264	297	33
	329	33	66	99	132	165	197	230	263	296	32
	328	33	66	98	131	164	197	230	262	295	32
	327	33	65	98	131	164	196	229	262	294	32
	326	33	65	98	130	163	196	228	261	293	32
	325	33	65	98	130	163	195	228	260	293	32
	324	32	65	97	130	162	194	227	259	292	32
	323	32	65	97	129	162	194	226	258	291	32
	322	32	64	97	129	161	193	225	258	290	32
	321	32	64	96	128	161	193	225	257	289	32
	320	32	64	96	128	160	192	224	256	288	32
	319	32	64	96	128	160	191	223	255	287	31
	318	32	64	95	127	159	191	223	254	286	31
	317	32	63	95	127	159	190	222	254	285	31
	316	32	63	95	126	158	190	221	253	284	31
	315	32	63	95	126	158	189	221	252	284	31
	314	31	63	94	126	157	188	220	251	283	31
	313	31	63	94	125	157	188	219	250	282	31
	312	31	62	94	125	156	187	218	250	281	31
	311	31	62	93	124	156	187	218	249	280	31
	310	31	62	93	124	155	186	217	248	279	31
	309	31	62	93	124	155	185	216	247	278	30
	308	31	62	92	123	154	185	216	246	277	30
	307	31	61	92	123	154	184	215	246	276	30
	Diff.	1	2	3	4	5	6	7	8	9	Di

N.	0	1	2	3	4	5	6	7	8	9	Diff.
140	146128	6438	6748	7058	7367	7676	7985	8294	8603	8911	309
141	9219	9527	9835	*0142	*0449	*0756	*1063	*1370	*1676	*1982	307
142	152288	2594	2900	3205	3510	3815	4120	4424	4728	5032	305
143	5336	5640	5943	6246	6549	6852	7154	7457	7759	8061	303
144	8362	8664	8965	9266	9567	9868	*0168	*0469	*0769	*1068	301
145	161368	1667	1967	2266	2564	2863	3161	3460	3758	4055	299
146	4353	4650	4947	5244	5541	5838	6134	6430	6726	7022	297
147	7317	7613	7908	8203	8497	8792	9086	9380	9674	9968	295
148	170262	0555	0848	1141	1434	1726	2019	2311	2603	2895	293
149	3186	3478	3769	4060	4351	4641	4932	5222	5512	5802	291
150	176091	6381	6670	6959	7248	7536	7825	8113	8401	8689	289
151	8977	9264	9552	9839	*0126	*0413	*0699	*0986	*1272	*1558	287
152	181844	2129	2415	2700	2985	3270	3555	3839	4123	4407	285
153	4691	4975	5259	5542	5825	6108	6391	6674	6956	7239	283
154	7521	7803	8084	8366	8647	8928	9209	9490	9771	*0051	281
155	190332	0612	0892	1171	1451	1730	2010	2289	2567	2846	279
156	3125	3403	3681	3959	4237	4514	4792	5069	5346	5623	278
157	5900	6176	6453	6729	7005	7281	7556	7832	8107	8382	276
158	8657	8932	9206	9481	9755	*0029	*0303	*0577	*0850	*1124	274
159	201397	1670	1943	2216	2488	2761	3033	3305	3577	3848	272

PROPORTIONAL PARTS

N.	Diff.	1	2	3	4	5	6	7	8	9	Diff.
	306	31	61	92	122	153	184	214	245	275	306
	305	31	61	92	122	153	183	214	244	275	305
	304	30	61	91	122	152	182	213	243	274	304
	303	30	61	91	121	152	182	212	242	273	303
	302	30	60	91	121	151	181	211	242	272	302
	301	30	60	90	120	151	181	211	241	271	301
	300	30	60	90	120	150	180	210	240	270	300
	299	30	60	90	120	150	179	209	239	269	299
	298	30	60	89	119	149	179	209	238	268	298
	297	30	59	89	119	149	178	208	238	267	297
	296	30	59	89	118	148	178	207	237	266	296
	295	30	59	89	118	148	177	207	236	266	295
	294	29	59	88	118	147	176	206	235	265	294
	293	29	59	88	117	147	176	205	234	264	293
	292	29	58	88	117	146	175	204	234	263	292
	291	29	58	87	116	146	175	204	233	262	291
	290	29	58	87	116	145	174	203	232	261	290
	289	29	58	87	116	145	173	202	231	260	289
	288	29	58	86	115	144	173	202	230	259	288
	287	29	57	86	115	144	172	201	230	258	287
	286	29	57	86	114	143	172	200	229	257	286
	285	29	57	86	114	143	171	200	228	257	285
	284	28	57	85	114	142	170	199	227	256	284
	283	28	57	85	113	142	170	198	226	255	283
	282	28	56	85	113	141	169	197	226	254	282
	281	28	56	84	112	141	169	197	225	253	281
	280	28	56	84	112	140	168	196	224	252	280
	279	28	56	84	112	140	167	195	223	251	279
	278	28	56	83	111	139	167	195	222	250	278
	277	28	55	83	111	139	166	194	222	249	277
	276	28	55	83	110	138	166	193	221	248	276
	275	28	55	83	110	138	165	193	220	248	275
	274	27	55	82	110	137	164	192	219	247	274
	273	27	55	82	109	137	164	191	218	246	273
	272	27	54	82	109	136	163	190	218	245	272
	271	27	54	81	108	136	163	190	217	244	271
	Diff.	1	2	3	4	5	6	7	8	9	Diff.

N.	0	1	2	3	4	5	6	7	8	9	Diff
160	204120	4391	4663	4934	5204	5475	5746	6016	6286	6556	271
161	6826	7096	7365	7634	7904	8173	8441	8710	8979	9247	269
162	9515	9783	*0051	*0319	*0586	*0853	*1121	*1388	*1654	*1921	267
163	212188	2454	2720	2986	3252	3518	3783	4049	4314	4579	266
164	4844	5109	5373	5638	5902	6166	6430	6694	6957	7221	264
165	217484	7747	8010	8273	8536	8798	9060	9323	9585	9846	262
166	220108	0370	0631	0892	1153	1414	1675	1936	2196	2456	261
167	2716	2976	3236	3496	3755	4015	4274	4533	4792	5051	259
168	5309	5568	5826	6084	6342	6600	6858	7115	7372	7630	258
169	7887	8144	8400	8657	8913	9170	9426	9682	9938	*0193	256
170	230449	0704	0960	1215	1470	1724	1979	2234	2488	2742	255
171	2996	3250	3504	3757	4011	4264	4517	4770	5023	5276	253
172	5528	5781	6033	6285	6537	6789	7041	7292	7544	7795	252
173	8046	8297	8548	8799	9049	9299	9550	9800	*0050	*0300	250
174	240549	0799	1048	1297	1546	1795	2044	2293	2541	2790	249
175	243038	3286	3534	3782	4030	4277	4525	4772	5019	5266	248
176	5513	5759	6006	6252	6499	6745	6991	7237	7482	7728	246
177	7973	8219	8464	8709	8954	9198	9443	9687	9932	*0176	245
178	250420	0664	0908	1151	1395	1638	1881	2125	2368	2610	243
179	2853	3096	3338	3580	3822	4064	4306	4548	4790	5031	242

N.	Diff.	1	2	3	4	5	6	7	8	9	Diff
PROPORTIONAL PARTS	272	27	54	82	109	136	163	190	218	245	272
	271	27	54	81	108	136	163	190	217	244	271
	270	27	54	81	108	135	162	189	216	243	27
	269	27	54	81	108	135	161	188	215	242	26
	268	27	54	80	107	134	161	188	214	241	26
	267	27	53	80	107	134	160	187	214	240	26
	266	27	53	80	106	133	160	186	213	239	26
	265	27	53	80	106	133	159	186	212	239	26
	264	26	53	79	106	132	158	185	211	238	26
	263	26	53	79	105	132	158	184	210	237	26
	262	26	52	79	105	131	157	183	210	236	26
	261	26	52	78	104	131	157	183	209	235	26
	260	26	52	78	104	130	156	182	208	234	26
	259	26	52	78	104	130	155	181	207	233	25
	258	26	52	77	103	129	155	181	206	232	25
	257	26	51	77	103	129	154	180	206	231	25
	256	26	51	77	102	128	154	179	205	230	25
	255	26	51	77	102	128	153	179	204	230	25
	254	25	51	76	102	127	152	178	203	229	25
	253	25	51	76	101	127	152	177	202	228	25
	252	25	50	76	101	126	151	176	202	227	25
	251	25	50	75	100	126	151	176	201	226	25
	250	25	50	75	100	125	150	175	200	225	25
	249	25	50	75	100	125	149	174	199	224	24
	248	25	50	74	99	124	149	174	198	223	24
	247	25	49	74	99	124	148	173	198	222	24
	246	25	49	74	98	123	148	172	197	221	24
	245	25	49	74	98	123	147	172	196	221	24
	244	24	49	73	98	122	146	171	195	220	24
	243	24	49	73	97	122	146	170	194	219	24
	242	24	48	73	97	121	145	169	194	218	24
	241	24	48	72	96	121	145	169	193	217	24
	240	24	48	72	96	120	144	168	192	216	24
	Diff.	1	2	3	4	5	6	7	8	9	Dif

N.	0	1	2	3	4	5	6	7	8	9	Diff.
180	255273	5514	5755	5996	6237	6477	6718	6958	7198	7439	241
181	7679	7918	8158	8398	8637	8877	9116	9355	9594	9833	239
182	260071	0310	0548	0787	1025	1263	1501	1739	1976	2214	238
183	2451	2688	2925	3162	3399	3636	3873	4109	4346	4582	237
184	4818	5054	5290	5525	5761	5996	6232	6467	6702	6937	235
185	267172	7406	7641	7875	8110	8344	8578	8812	9046	9279	234
186	9513	9746	9980	*0213	*0446	*0679	*0912	*1144	*1377	*1609	233
187	271842	2074	2306	2538	2770	3001	3233	3464	3696	3927	232
188	4158	4389	4620	4850	5081	5311	5542	5772	6002	6232	230
189	6462	6692	6921	7151	7380	7609	7838	8067	8296	8525	229
190	278754	8982	9211	9439	9667	9895	*0123	*0351	*0578	*0806	228
191	281033	1261	1488	1715	1942	2169	2396	2622	2849	3075	227
192	3301	3527	3753	3979	4205	4431	4656	4882	5107	5332	226
193	5557	5782	6007	6232	6456	6681	6905	7130	7354	7578	225
194	7802	8026	8249	8473	8696	8920	9143	9366	9589	9812	223
195	290035	0257	0480	0702	0925	1147	1369	1591	1813	2034	222
196	2256	2478	2699	2920	3141	3363	3584	3804	4025	4246	221
197	4466	4687	4907	5127	5347	5567	5787	6007	6226	6446	220
198	6665	6884	7104	7323	7542	7761	7979	8198	8416	8635	219
199	8853	9071	9289	9507	9725	9943	*0161	*0378	*0595	*0813	218
200	301030	1247	1464	1681	1898	2114	2331	2547	2764	2980	217
201	3196	3412	3628	3844	4059	4275	4491	4706	4921	5136	216
202	5351	5566	5781	5996	6211	6425	6639	6854	7068	7282	215
203	7496	7710	7924	8137	8351	8564	8778	8991	9204	9417	213
204	9630	9843	*0056	*0268	*0481	*0693	*0906	*1118	*1330	*1542	212

PROPORTIONAL PARTS

N.	Diff.	1	2	3	4	5	6	7	8	9	Diff.
	239	24	48	72	96	120	143	167	191	215	239
	238	24	48	71	95	119	143	167	190	214	238
	237	24	47	71	95	119	142	166	190	213	237
	236	24	47	71	94	118	142	165	189	212	236
	235	24	47	71	94	118	141	165	188	212	235
	234	23	47	70	94	117	140	164	187	211	234
	233	23	47	70	93	117	140	163	186	210	233
	232	23	46	70	93	116	139	162	186	209	232
	231	23	46	69	92	116	139	162	185	208	231
	230	23	46	69	92	115	138	161	184	207	230
	229	23	46	69	92	115	137	160	183	206	229
	228	23	46	68	91	114	137	160	182	205	228
	227	23	45	68	91	114	136	159	182	204	227
	226	23	45	68	90	113	136	158	181	203	226
	225	23	45	68	90	113	135	158	180	203	225
	224	22	45	67	90	112	134	157	179	202	224
	223	22	45	67	89	112	134	156	178	201	223
	222	22	44	67	89	111	133	155	178	200	222
	221	22	44	66	88	111	133	155	177	199	221
	220	22	44	66	88	110	132	154	176	198	220
	219	22	44	66	88	110	131	153	175	197	219
	218	22	44	65	87	109	131	153	174	196	218
	217	22	43	65	87	109	130	152	174	195	217
	216	22	43	65	86	108	130	151	173	194	216
	215	22	43	65	86	108	129	151	172	194	215
	214	21	43	64	86	107	128	150	171	193	214
	213	21	43	64	85	107	128	149	170	192	213
	212	21	42	64	85	106	127	148	170	191	212
	Diff.	1	2	3	4	5	6	7	8	9	Diff.

N.	0	1	2	3	4	5	6	7	8	9	Diff.
205	311754	1966	2177	2389	2600	2812	3023	3234	3445	3656	211
206	3867	4078	4289	4499	4710	4920	5130	5340	5551	5760	210
207	5970	6180	6390	6599	6809	7018	7227	7436	7646	7854	209
208	8063	8272	8481	8689	8898	9106	9314	9522	9730	9938	208
209	320146	0354	0562	0769	0977	1184	1391	1598	1805	2012	207
210	322219	2426	2633	2839	3046	3252	3458	3665	3871	4077	206
211	4282	4488	4694	4899	5105	5310	5516	5721	5926	6131	205
212	6336	6541	6745	6950	7155	7359	7563	7767	7972	8176	204
213	8380	8583	8787	8991	9194	9398	9601	9805	*0008	*0211	203
214	330414	0617	0819	1022	1225	1427	1630	1832	2034	2236	202
215	332438	2640	2842	3044	3246	3447	3649	3850	4051	4253	202
216	4454	4655	4856	5057	5257	5458	5658	5859	6059	6260	201
217	6460	6660	6860	7060	7260	7459	7659	7858	8058	8257	200
218	8456	8656	8855	9054	9253	9451	9650	9849	*0047	*0246	199
219	340444	0642	0841	1039	1237	1435	1632	1830	2028	2225	198
220	342423	2620	2817	3014	3212	3409	3606	3802	3999	4196	197
221	4392	4589	4785	4981	5178	5374	5570	5766	5962	6157	196
222	6353	6549	6744	6939	7135	7330	7525	7720	7915	8110	195
223	8305	8500	8694	8889	9083	9278	9472	9666	9860	*0054	194
224	350248	0442	0636	0829	1023	1216	1410	1603	1796	1989	193
225	352183	2375	2568	2761	2954	3147	3339	3532	3724	3916	193
226	4108	4301	4493	4685	4876	5068	5260	5452	5643	5834	192
227	6026	6217	6408	6599	6790	6981	7172	7363	7554	7744	191
228	7935	8125	8316	8506	8696	8886	9076	9266	9456	9646	190
229	9835	*0025	*0215	*0404	*0593	*0783	*0972	*1161	*1350	*1539	189
230	361728	1917	2105	2294	2482	2671	2859	3048	3236	3424	188
231	3612	3800	3988	4176	4363	4551	4739	4926	5113	5301	188
232	5488	5675	5862	6049	6236	6423	6610	6796	6983	7169	187
233	7356	7542	7729	7915	8101	8287	8473	8659	8845	9030	186
234	9216	9401	9587	9772	9958	*0143	*0328	*0513	*0698	*0883	185

N.	Diff.	1	2	3	4	5	6	7	8	9	Diff
PROPORTIONAL PARTS	212	21	42	64	85	106	127	148	170	191	212
	211	21	42	63	84	106	127	148	169	190	211
	210	21	42	63	84	105	126	147	168	189	210
	209	21	42	63	84	105	125	146	167	188	209
	208	21	42	62	83	104	125	146	166	187	208
	207	21	41	62	83	104	124	145	166	186	207
	206	21	41	62	82	103	124	144	165	185	206
	205	21	41	62	82	103	123	144	164	185	205
	204	20	41	61	82	102	122	143	163	184	204
	203	20	41	61	81	102	122	142	162	183	203
	202	20	40	61	81	101	121	141	162	182	202
	201	20	40	60	80	101	121	141	161	181	201
	200	20	40	60	80	100	120	140	160	180	200
	199	20	40	60	80	100	119	139	159	179	199
	198	20	40	59	79	99	119	139	158	178	198
	197	20	39	59	79	99	118	138	158	177	197
	196	20	39	59	78	98	118	137	157	176	196
	195	20	39	59	78	98	117	137	156	176	195
	194	19	39	58	78	97	116	136	155	175	194
	193	19	39	58	77	97	116	135	154	174	193
	192	19	38	58	77	96	115	134	154	173	192
	191	19	38	57	76	96	115	134	153	172	191
	190	19	38	57	76	95	114	133	152	171	190
	189	19	38	57	76	95	113	132	151	170	189
	188	19	38	56	75	94	113	132	150	169	188
	Diff.	1	2	3	4	5	6	7	8	9	Diff.

N.	0	1	2	3	4	5	6	7	8	9	Diff.
235	371068	1253	1437	1622	1806	1991	2175	2360	2544	2728	184
236	2912	3096	3280	3464	3647	3831	4015	4198	4382	4565	184
237	4748	4932	5115	5298	5481	5664	5846	6029	6212	6394	183
238	6577	6759	6942	7124	7306	7488	7670	7852	8034	8216	182
239	8398	8580	8761	8943	9124	9306	9487	9668	9849	*0030	181
240	380211	0392	0573	0754	0934	1115	1296	1476	1656	1837	181
241	2017	2197	2377	2557	2737	2917	3097	3277	3456	3636	180
242	3815	3995	4174	4353	4533	4712	4891	5070	5249	5428	179
243	5606	5785	5964	6142	6321	6499	6677	6856	7034	7212	178
244	7390	7568	7746	7923	8101	8279	8456	8634	8811	8989	178
245	389166	9343	9520	9698	9875	*0051	*0228	*0405	*0582	*0759	177
246	390935	1112	1288	1464	1641	1817	1993	2169	2345	2521	176
247	2697	2873	3048	3224	3400	3575	3751	3926	4101	4277	176
248	4452	4627	4802	4977	5152	5326	5501	5676	5850	6025	175
249	6199	6374	6548	6722	6896	7071	7245	7419	7592	7766	174
250	397940	8114	8287	8461	8634	8808	8981	9154	9328	9501	173
251	9674	9847	*0020	*0192	*0365	*0538	*0711	*0883	*1056	*1228	173
252	401401	1573	1745	1917	2089	2261	2433	2605	2777	2949	172
253	3121	3292	3464	3635	3807	3978	4149	4320	4492	4663	171
254	4834	5005	5176	5346	5517	5688	5858	6029	6199	6370	171
255	406540	6710	6881	7051	7221	7391	7561	7731	7901	8070	170
256	8240	8410	8579	8749	8918	9087	9257	9426	9595	9764	169
257	9933	*0102	*0271	*0440	*0609	*0777	*0946	*1114	*1283	*1451	169
258	411620	1788	1956	2124	2293	2461	2629	2796	2964	3132	168
259	3300	3467	3635	3803	3970	4137	4305	4472	4639	4806	167
260	414973	5140	5307	5474	5641	5808	5974	6141	6308	6474	167
261	6641	6807	6973	7139	7306	7472	7638	7804	7970	8135	166
262	8301	8467	8633	8798	8964	9129	9295	9460	9625	9791	165
263	9956	*0121	*0286	*0451	*0616	*0781	*0945	*1110	*1275	*1439	165
264	421604	1768	1933	2097	2261	2426	2590	2754	2918	3082	164

PROPORTIONAL PARTS

N.	Diff.	1	2	3	4	5	6	7	8	9	Diff.
	187	19	37	56	75	94	112	131	150	168	187
	186	19	37	56	74	93	112	130	149	167	186
	185	19	37	56	74	93	111	130	148	167	185
	184	18	37	55	74	92	110	129	147	166	184
	183	18	37	55	73	92	110	128	146	165	183
	182	18	36	55	73	91	109	127	146	164	182
	181	18	36	54	72	91	109	127	145	163	181
	180	18	36	54	72	90	108	126	144	162	180
	179	18	36	54	72	90	107	125	143	161	179
	178	18	36	53	71	89	107	125	142	160	178
	177	18	35	53	71	89	106	124	142	159	177
	176	18	35	53	70	88	106	123	141	158	176
	175	18	35	53	70	88	105	123	140	158	175
	174	17	35	52	70	87	104	122	139	157	174
	173	17	35	52	69	87	104	121	138	156	173
	172	17	34	52	69	86	103	120	138	155	172
	171	17	34	51	68	86	103	120	137	154	171
	170	17	34	51	68	85	102	119	136	153	170
	169	17	34	51	68	85	101	118	135	152	169
	168	17	34	50	67	84	101	118	134	151	168
	167	17	33	50	67	84	100	117	134	150	167
	166	17	33	50	66	83	100	116	133	149	166
	165	17	33	50	66	83	99	116	132	149	165
	164	16	33	49	66	82	98	115	131	148	164
	Diff.	1	2	3	4	5	6	7	8	9	Diff.

N.	0	1	2	3	4	5	6	7	8	9	Diff
265	423246	3410	3574	3737	3901	4065	4228	4392	4555	4718	164
266	4882	5045	5208	5371	5534	5697	5860	6023	6186	6349	163
267	6511	6674	6836	6999	7161	7324	7486	7648	7811	7973	162
268	8135	8297	8459	8621	8783	8944	9106	9268	9429	9591	162
269	9752	9914	*0075	*0236	*0398	*0559	*0720	*0881	*1042	*1203	161
270	431364	1525	1685	1846	2007	2167	2328	2488	2649	2809	161
271	2969	3130	3290	3450	3610	3770	3930	4090	4249	4409	160
272	4569	4729	4888	5048	5207	5367	5526	5685	5844	6004	159
273	6163	6322	6481	6640	6799	6957	7116	7275	7433	7592	159
274	7751	7909	8067	8226	8384	8542	8701	8859	9017	9175	158
275	439333	9491	9648	9806	9964	*0122	*0279	*0437	*0594	*0752	158
276	440909	1066	1224	1381	1538	1695	1852	2009	2166	2323	157
277	2480	2637	2793	2950	3106	3263	3419	3576	3732	3889	157
278	4045	4201	4357	4513	4669	4825	4981	5137	5293	5449	156
279	5604	5760	5915	6071	6226	6382	6537	6692	6848	7003	155
280	447158	7313	7468	7623	7778	7933	8088	8242	8397	8552	155
281	8706	8861	9015	9170	9324	9478	9633	9787	9941	*0095	154
282	450249	0403	0557	0711	0865	1018	1172	1326	1479	1633	154
283	1786	1940	2093	2247	2400	2553	2706	2859	3012	3165	153
284	3318	3471	3624	3777	3930	4082	4235	4387	4540	4692	153
285	454845	4997	5150	5302	5454	5606	5758	5910	6062	6214	152
286	6366	6518	6670	6821	6973	7125	7276	7428	7579	7731	152
287	7882	8033	8184	8336	8487	8638	8789	8940	9091	9242	151
288	9392	9543	9694	9845	9995	*0146	*0296	*0447	*0597	*0748	151
289	460898	1048	1198	1348	1499	1649	1799	1948	2098	2248	150
290	462398	2548	2697	2847	2997	3146	3296	3445	3594	3744	150
291	3893	4042	4191	4340	4490	4639	4788	4936	5085	5234	149
292	5383	5532	5680	5829	5977	6126	6274	6423	6571	6719	149
293	6868	7016	7164	7312	7460	7608	7756	7904	8052	8200	148
294	8347	8495	8643	8790	8938	9085	9233	9380	9527	9675	148
295	469822	9969	*0116	*0263	*0410	*0557	*0704	*0851	*0998	*1145	147
296	471292	1438	1585	1732	1878	2025	2171	2318	2464	2610	146
297	2756	2903	3049	3195	3341	3487	3633	3779	3925	4071	146
298	4216	4362	4508	4653	4799	4944	5090	5235	5381	5526	146
299	5671	5816	5962	6107	6252	6397	6542	6687	6832	6976	145

N.	Diff.	1	2	3	4	5	6	7	8	9	Diff
PROPORTIONAL PARTS	164	16	33	49	66	82	98	115	131	148	164
	163	16	33	49	65	82	98	114	130	147	163
	162	16	32	49	65	81	97	113	130	146	162
	161	16	32	48	64	81	97	113	129	145	161
	160	16	32	48	64	80	96	112	128	144	160
	159	16	32	48	64	80	95	111	127	143	159
	158	16	32	47	63	79	95	111	126	142	158
	157	16	31	47	63	79	94	110	126	141	157
	156	16	31	47	62	78	94	109	125	140	156
	155	16	31	47	62	78	93	109	124	140	155
	154	15	31	46	62	77	92	108	123	139	154
	153	15	31	46	61	77	92	107	122	138	153
	152	15	30	46	61	76	91	106	122	137	152
	151	15	30	45	60	76	91	106	121	136	151
	150	15	30	45	60	75	90	105	120	135	150
	149	15	30	45	60	75	89	104	119	134	149
	148	15	30	44	59	74	89	104	118	133	148
	147	15	29	44	59	74	88	103	118	132	147
	146	15	29	44	58	73	88	102	117	131	146
	145	15	29	44	58	73	87	102	116	131	145
	144	14	29	43	58	72	86	101	115	130	144
	143	14	29	43	57	72	86	100	114	129	143
	Diff.	1	2	3	4	5	6	7	8	9	Diff

N.	0	1	2	3	4	5	6	7	8	9	Diff.
300	477121	7266	7411	7555	7700	7844	7989	8133	8278	8422	145
301	8566	8711	8855	8999	9143	9287	9431	9575	9719	9863	144
302	480007	0151	0294	0438	0582	0725	0869	1012	1156	1299	144
303	1443	1586	1729	1872	2016	2159	2302	2445	2588	2731	143
304	2874	3016	3159	3302	3445	3587	3730	3872	4015	4157	143
305	484300	4442	4585	4727	4869	5011	5153	5295	5437	5579	142
306	5721	5863	6005	6147	6289	6430	6572	6714	6855	6997	142
307	7138	7280	7421	7563	7704	7845	7986	8127	8269	8410	141
308	8551	8692	8833	8974	9114	9255	9396	9537	9677	9818	141
309	9958	*0099	*0239	*0380	*0520	*0661	*0801	*0941	*1081	*1222	140
310	491362	1502	1642	1782	1922	2062	2201	2341	2481	2621	140
311	2760	2900	3040	3179	3319	3458	3597	3737	3876	4015	139
312	4155	4294	4433	4572	4711	4850	4989	5128	5267	5406	139
313	5544	5683	5822	5960	6099	6238	6376	6515	6653	6791	139
314	6930	7068	7206	7344	7483	7621	7759	7897	8035	8173	138
315	498311	8448	8586	8724	8862	8999	9137	9275	9412	9550	138
316	9687	9824	9962	*0099	*0236	*0374	*0511	*0648	*0785	*0922	137
317	501059	1196	1333	1470	1607	1744	1880	2017	2154	2291	137
318	2427	2564	2700	2837	2973	3109	3246	3382	3518	3655	136
319	3791	3927	4063	4199	4335	4471	4607	4743	4878	5014	136
320	505150	5286	5421	5557	5693	5828	5964	6099	6234	6370	136
321	6505	6640	6776	6911	7046	7181	7316	7451	7586	7721	135
322	7856	7991	8126	8260	8395	8530	8664	8799	8934	9068	135
323	9203	9337	9471	9606	9740	9874	*0009	*0143	*0277	*0411	134
324	510545	0679	0813	0947	1081	1215	1349	1482	1616	1750	134
325	511883	2017	2151	2284	2418	2551	2684	2818	2951	3084	133
326	3218	3351	3484	3617	3750	3883	4016	4149	4282	4415	133
327	4548	4681	4813	4946	5079	5211	5344	5476	5609	5741	133
328	5874	6006	6139	6271	6403	6535	6668	6800	6932	7064	132
329	7196	7328	7460	7592	7724	7855	7987	8119	8251	8382	132
330	518514	8646	8777	8909	9040	9171	9303	9434	9566	9697	131
331	9828	9959	*0090	*0221	*0353	*0484	*0615	*0745	*0876	*1007	131
332	521138	1269	1400	1530	1661	1792	1922	2053	2183	2314	131
333	2444	2575	2705	2835	2966	3096	3226	3356	3486	3616	130
334	3746	3876	4006	4136	4266	4396	4526	4656	4785	4915	130
335	525045	5174	5304	5434	5563	5693	5822	5951	6081	6210	129
336	6339	6469	6598	6727	6856	6985	7114	7243	7372	7501	129
337	7630	7759	7888	8016	8145	8274	8402	8531	8660	8788	129
338	8917	9045	9174	9302	9430	9559	9687	9815	9943	*0072	128
339	530200	0328	0456	0584	0712	0840	0968	1096	1223	1351	128

N.	Diff.	1	2	3	4	5	6	7	8	9	Diff.
PROPORTIONAL PARTS	142	14	28	43	57	71	85	99	114	128	142
	141	14	28	42	56	71	85	99	113	127	141
	140	14	28	42	56	70	84	98	112	126	140
	139	14	28	42	56	70	83	97	111	125	139
	138	14	28	41	55	69	83	97	110	124	138
	137	14	27	41	55	69	82	96	110	123	137
	136	14	27	41	54	68	82	95	109	122	136
	135	14	27	41	54	68	81	95	108	122	135
	134	13	27	40	54	67	80	94	107	121	134
	133	13	27	40	53	67	80	93	106	120	133
	132	13	26	40	53	66	79	92	106	119	132
	131	13	26	39	52	66	79	92	105	118	131
	130	13	26	39	52	65	78	91	104	117	130
	129	13	26	39	52	65	77	90	103	116	129
	128	13	26	38	51	64	77	90	102	115	128
	127	13	25	38	51	64	76	89	102	114	127
	Diff.	1	2	3	4	5	6	7	8	9	Diff.

N.	0	1	2	3	4	5	6	7	8	9	Dif
340	531479	1607	1734	1862	1990	2117	2245	2372	2500	2627	12
341	2754	2882	3009	3136	3264	3391	3518	3645	3772	3899	12
342	4026	4153	4280	4407	4534	4661	4787	4914	5041	5167	12
343	5294	5421	5547	5674	5800	5927	6053	6180	6306	6432	12
344	6558	6685	6811	6937	7063	7189	7315	7441	7567	7693	12
345	537819	7945	8071	8197	8322	8448	8574	8699	8825	8951	12
346	9076	9202	9327	9452	9578	9703	9829	9954	*0079	*0204	12
347	540329	0455	0580	0705	0830	0955	1080	1205	1330	1454	12
348	1579	1704	1829	1953	2078	2203	2327	2452	2576	2701	12
349	2825	2950	3074	3199	3323	3447	3571	3696	3820	3944	12
350	544068	4192	4316	4440	4564	4688	4812	4936	5060	5183	12
351	5307	5431	5555	5678	5802	5925	6049	6172	6296	6419	12
352	6543	6666	6789	6913	7036	7159	7282	7405	7529	7652	12
353	7775	7898	8021	8144	8267	8389	8512	8635	8758	8881	12
354	9003	9126	9249	9371	9494	9616	9739	9861	9984	*0106	12
355	550228	0351	0473	0595	0717	0840	0962	1084	1206	1328	12
356	1450	1572	1694	1816	1938	2060	2181	2303	2425	2547	12
357	2668	2790	2911	3033	3155	3276	3398	3519	3640	3762	12
358	3883	4004	4126	4247	4368	4489	4610	4731	4852	4973	12
359	5094	5215	5336	5457	5578	5699	5820	5940	6061	6182	12
360	556303	6423	6544	6664	6785	6905	7026	7146	7267	7387	12
361	7507	7627	7748	7868	7988	8108	8228	8349	8469	8589	12
362	8709	8829	8948	9068	9188	9308	9428	9548	9667	9787	12
363	9907	*0026	*0146	*0265	*0385	*0504	*0624	*0743	*0863	*0982	11
364	561101	1221	1340	1459	1578	1698	1817	1936	2055	2174	11
365	562293	2412	2531	2650	2769	2887	3006	3125	3244	3362	11
366	3481	3600	3718	3837	3955	4074	4192	4311	4429	4548	11
367	4666	4784	4903	5021	5139	5257	5376	5494	5612	5730	11
368	5848	5966	6084	6202	6320	6437	6555	6673	6791	6909	11
369	7026	7144	7262	7379	7497	7614	7732	7849	7967	8084	11
370	568202	8319	8436	8554	8671	8788	8905	9023	9140	9257	11
371	9374	9491	9608	9725	9842	9959	*0076	*0193	*0309	*0426	11
372	570543	0660	0776	0893	1010	1126	1243	1359	1476	1592	11
373	1709	1825	1942	2058	2174	2291	2407	2523	2639	2755	11
374	2872	2988	3104	3220	3336	3452	3568	3684	3800	3915	11
375	574031	4147	4263	4379	4494	4610	4726	4841	4957	5072	11
376	5188	5303	5419	5534	5650	5765	5880	5996	6111	6226	11
377	6341	6457	6572	6687	6802	6917	7032	7147	7262	7377	11
378	7492	7607	7722	7836	7951	8066	8181	8295	8410	8525	11
379	8639	8754	8868	8983	9097	9212	9326	9441	9555	9669	11

N.	Diff.	1	2	3	4	5	6	7	8	9	Dif
PROP. PARTS	128	13	26	38	51	64	77	90	102	115	128
	127	13	25	38	51	64	76	89	102	114	127
	126	13	25	38	50	63	76	88	101	113	126
	125	13	25	38	50	63	75	88	100	113	125
	124	12	25	37	50	62	74	87	99	112	124
	123	12	25	37	49	62	74	86	98	111	123
	122	12	24	37	49	61	73	85	98	110	122
	121	12	24	36	48	61	73	85	97	109	121
	120	12	24	36	48	60	72	84	96	108	120
	119	12	24	36	48	60	71	83	95	107	119
	118	12	24	35	47	59	71	83	94	106	118
	117	12	23	35	47	59	70	82	94	105	117
	116	12	23	35	46	58	70	81	93	104	116
	Diff.	1	2	3	4	5	6	7	8	9	Diff

N.	0	1	2	3	4	5	6	7	8	9	Diff.
380	579784	9898	*0012	*0126	*0241	*0355	*0469	*0583	*0697	*0811	114
381	580925	1039	1153	1267	1381	1495	1608	1722	1836	1950	114
382	2063	2177	2291	2404	2518	2631	2745	2858	2972	3085	114
383	3199	3312	3426	3539	3652	3765	3879	3992	4105	4218	113
384	4331	4444	4557	4670	4783	4896	5009	5122	5235	5348	113
385	585461	5574	5686	5799	5912	6024	6137	6250	6362	6475	113
386	6587	6700	6812	6925	7037	7149	7262	7374	7486	7599	112
387	7711	7823	7935	8047	8160	8272	8384	8496	8608	8720	112
388	8832	8944	9056	9167	9279	9391	9503	9615	9726	9838	112
389	9950	*0061	*0173	*0284	*0396	*0507	*0619	*0730	*0842	*0953	112
390	591065	1176	1287	1399	1510	1621	1732	1843	1955	2066	111
391	2177	2288	2399	2510	2621	2732	2843	2954	3064	3175	111
392	3286	3397	3508	3618	3729	3840	3950	4061	4171	4282	111
393	4393	4503	4614	4724	4834	4945	5055	5165	5276	5386	110
394	5496	5606	5717	5827	5937	6047	6157	6267	6377	6487	110
395	596597	6707	6817	6927	7037	7146	7256	7366	7476	7586	110
396	7695	7805	7914	8024	8134	8243	8353	8462	8572	8681	110
397	8791	8900	9009	9119	9228	9337	9446	9556	9665	9774	109
398	9883	9992	*0101	*0210	*0319	*0428	*0537	*0646	*0755	*0864	109
399	600973	1082	1191	1299	1408	1517	1625	1734	1843	1951	109
400	602060	2169	2277	2386	2494	2603	2711	2819	2928	3036	108
401	3144	3253	3361	3469	3577	3686	3794	3902	4010	4118	108
402	4226	4334	4442	4550	4658	4766	4874	4982	5089	5197	108
403	5305	5413	5521	5628	5736	5844	5951	6059	6166	6274	108
404	6381	6489	6596	6704	6811	6919	7026	7133	7241	7348	107
405	607455	7562	7669	7777	7884	7991	8098	8205	8312	8419	107
406	8526	8633	8740	8847	8954	9061	9167	9274	9381	9488	107
407	9594	9701	9808	9914	*0021	*0128	*0234	*0341	*0447	*0554	107
408	610660	0767	0873	0979	1086	1192	1298	1405	1511	1617	106
409	1723	1829	1936	2042	2148	2254	2360	2466	2572	2678	106
410	612784	2890	2996	3102	3207	3313	3419	3525	3630	3736	106
411	3842	3947	4053	4159	4264	4370	4475	4581	4686	4792	106
412	4897	5003	5108	5213	5319	5424	5529	5634	5740	5845	105
413	5950	6055	6160	6265	6370	6476	6581	6686	6790	6895	105
414	7000	7105	7210	7315	7420	7525	7629	7734	7839	7943	105
415	618048	8153	8257	8362	8466	8571	8676	8780	8884	8989	105
416	9093	9198	9302	9406	9511	9615	9719	9824	9928	*0032	104
417	620136	0240	0344	0448	0552	0656	0760	0864	0968	1072	104
418	1176	1280	1384	1488	1592	1695	1799	1903	2007	2110	104
419	2214	2318	2421	2525	2628	2732	2835	2939	3042	3146	104

N.	Diff.	1	2	3	4	5	6	7	8	9	Diff.
PROP. PARTS	115	12	23	35	46	58	69	81	92	104	115
	114	11	23	34	46	57	68	80	91	103	114
	113	11	23	34	45	57	68	79	90	102	113
	112	11	22	34	45	56	67	78	90	101	112
	111	11	22	33	44	56	67	78	89	100	111
	110	11	22	33	44	55	66	77	88	99	110
	109	11	22	33	44	55	65	76	87	98	109
	108	11	22	32	43	54	65	76	86	97	108
	107	11	21	32	43	54	64	75	86	96	107
	106	11	21	32	42	53	64	74	85	95	106
	105	11	21	32	42	53	63	74	84	95	105
	104	10	21	31	42	52	62	73	83	94	104
	103	10	21	31	41	52	62	72	82	93	103
	Diff.	1	2	3	4	5	6	7	8	9	Diff.

N.	0	1	2	3	4	5	6	7	8	9	Diff.
420	623249	3353	3456	3559	3663	3766	3869	3973	4076	4179	103
421	4282	4385	4488	4591	4695	4798	4901	5004	5107	5210	103
422	5312	5415	5518	5621	5724	5827	5929	6032	6135	6238	103
423	6340	6443	6546	6648	6751	6853	6956	7058	7161	7263	103
424	7366	7468	7571	7673	7775	7878	7980	8082	8185	8287	102
425	628389	8491	8593	8695	8797	8900	9002	9104	9206	9308	102
426	9410	9512	9613	9715	9817	9919	*0021	*0123	*0224	*0326	102
427	630428	0530	0631	0733	0835	0936	1038	1139	1241	1342	102
428	1444	1545	1647	1748	1849	1951	2052	2153	2255	2356	101
429	2457	2559	2660	2761	2862	2963	3064	3165	3266	3367	101
430	633468	3569	3670	3771	3872	3973	4074	4175	4276	4376	101
431	4477	4578	4679	4779	4880	4981	5081	5182	5283	5383	101
432	5484	5584	5685	5785	5886	5986	6087	6187	6287	6388	100
433	6488	6588	6688	6789	6889	6989	7089	7189	7290	7390	100
434	7490	7590	7690	7790	7890	7990	8090	8190	8290	8389	100
435	638489	8589	8689	8789	8888	8988	9088	9188	9287	9387	100
436	9486	9586	9686	9785	9885	9984	*0084	*0183	*0283	*0382	99
437	640481	0581	0680	0779	0879	0978	1077	1177	1276	1375	99
438	1474	1573	1672	1771	1871	1970	2069	2168	2267	2366	99
439	2465	2563	2662	2761	2860	2959	3058	3156	3255	3354	99
440	643453	3551	3650	3749	3847	3946	4044	4143	4242	4340	98
441	4439	4537	4636	4734	4832	4931	5029	5127	5226	5324	98
442	5422	5521	5619	5717	5815	5913	6011	6110	6208	6306	98
443	6404	6502	6600	6698	6796	6894	6992	7089	7187	7285	98
444	7383	7481	7579	7676	7774	7872	7969	8067	8165	8262	98
445	648360	8458	8555	8653	8750	8848	8945	9043	9140	9237	97
446	9335	9432	9530	9627	9724	9821	9919	*0016	*0113	*0210	97
447	650308	0405	0502	0599	0696	0793	0890	0987	1084	1181	97
448	1278	1375	1472	1569	1666	1762	1859	1956	2053	2150	97
449	2246	2343	2440	2536	2633	2730	2826	2923	3019	3116	97
450	653213	3309	3405	3502	3598	3695	3791	3888	3984	4080	96
451	4177	4273	4369	4465	4562	4658	4754	4850	4946	5042	96
452	5138	5235	5331	5427	5523	5619	5715	5810	5906	6002	96
453	6098	6194	6290	6386	6482	6577	6673	6769	6864	6960	96
454	7056	7152	7247	7343	7438	7534	7629	7725	7820	7916	96
455	658011	8107	8202	8298	8393	8488	8584	8679	8774	8870	95
456	8965	9060	9155	9250	9346	9441	9536	9631	9726	9821	95
457	9916	*0011	*0106	*0201	*0296	*0391	*0486	*0581	*0676	*0771	95
458	660865	0960	1055	1150	1245	1339	1434	1529	1623	1718	95
459	1813	1907	2002	2096	2191	2286	2380	2475	2569	2663	95
460	662758	2852	2947	3041	3135	3230	3324	3418	3512	3607	94
461	3701	3795	3889	3983	4078	4172	4266	4360	4454	4548	94
462	4642	4736	4830	4924	5018	5112	5206	5299	5393	5487	94
463	5581	5675	5769	5862	5956	6050	6143	6237	6331	6424	94
464	6518	6612	6705	6799	6892	6986	7079	7173	7266	7360	94

N.	Diff.	1	2	3	4	5	6	7	8	9	Diff.
PROP. PARTS	104	10	21	31	42	52	62	73	83	94	104
	103	10	21	31	41	52	62	72	82	93	103
	102	10	20	31	41	51	61	71	82	92	102
	101	10	20	30	40	51	61	71	81	91	101
	100	10	20	30	40	50	60	70	80	90	100
	99	10	20	30	40	50	59	69	79	89	99
	98	10	20	29	39	49	59	69	78	88	98
	97	10	19	29	39	49	58	68	78	87	97
	96	10	19	29	38	48	58	67	77	86	96
	95	10	19	29	38	48	57	67	76	86	95
	Diff.	1	2	3	4	5	6	7	8	9	Diff.

N.	0	1	2	3	4	5	6	7	8	9	Diff.
65	667453	7546	7640	7733	7826	7920	8013	8106	8199	8293	93
66	8386	8479	8572	8665	8759	8852	8945	9038	9131	9224	93
67	9317	9410	9503	9596	9689	9782	9875	9967	*0060	*0153	93
68	670246	0339	0431	0524	0617	0710	0802	0895	0988	1080	93
69	1173	1265	1358	1451	1543	1636	1728	1821	1913	2005	93
70	672098	2190	2283	2375	2467	2560	2652	2744	2836	2929	92
71	3021	3113	3205	3297	3390	3482	3574	3666	3758	3850	92
72	3942	4034	4126	4218	4310	4402	4494	4586	4677	4769	92
73	4861	4953	5045	5137	5228	5320	5412	5503	5595	5687	92
74	5778	5870	5962	6053	6145	6236	6328	6419	6511	6602	92
75	676694	6785	6876	6968	7059	7151	7242	7333	7424	7516	91
76	7607	7698	7789	7881	7972	8063	8154	8245	8336	8427	91
77	8518	8609	8700	8791	8882	8973	9064	9155	9246	9337	91
78	9428	9519	9610	9700	9791	9882	9973	*0063	*0154	*0245	91
79	680336	0426	0517	0607	0698	0789	0879	0970	1060	1151	91
80	681241	1332	1422	1513	1603	1693	1784	1874	1964	2055	90
81	2145	2235	2326	2416	2506	2596	2686	2777	2867	2957	90
82	3047	3137	3227	3317	3407	3497	3587	3677	3767	3857	90
83	3947	4037	4127	4217	4307	4396	4486	4576	4666	4756	90
84	4845	4935	5025	5114	5204	5294	5383	5473	5563	5652	90
85	685742	5831	5921	6010	6100	6189	6279	6368	6458	6547	89
86	6636	6726	6815	6904	6994	7083	7172	7261	7351	7440	89
87	7529	7618	7707	7796	7886	7975	8064	8153	8242	8331	89
88	8420	8509	8598	8687	8776	8865	8953	9042	9131	9220	89
89	9309	9398	9486	9575	9664	9753	9841	9930	*0019	*0107	89
90	690196	0285	0373	0462	0550	0639	0728	0816	0905	0993	89
91	1081	1170	1258	1347	1435	1524	1612	1700	1789	1877	88
92	1965	2053	2142	2230	2318	2406	2494	2583	2671	2759	88
93	2847	2935	3023	3111	3199	3287	3375	3463	3551	3639	88
94	3727	3815	3903	3991	4078	4166	4254	4342	4430	4517	88
95	694605	4693	4781	4868	4956	5044	5131	5219	5307	5394	88
96	5482	5569	5657	5744	5832	5919	6007	6094	6182	6269	87
97	6356	6444	6531	6618	6706	6793	6880	6968	7055	7142	87
98	7229	7317	7404	7491	7578	7665	7752	7839	7926	8014	87
99	8101	8188	8275	8362	8449	8535	8622	8709	8796	8883	87
00	698970	9057	9144	9231	9317	9404	9491	9578	9664	9751	87
01	9838	9924	*0011	*0098	*0184	*0271	*0358	*0444	*0531	*0617	87
02	700704	0790	0877	0963	1050	1136	1222	1309	1395	1482	86
03	1568	1654	1741	1827	1913	1999	2086	2172	2258	2344	86
04	2431	2517	2603	2689	2775	2861	2947	3033	3119	3205	86
05	703291	3377	3463	3549	3635	3721	3807	3893	3979	4065	86
06	4151	4236	4322	4408	4494	4579	4665	4751	4837	4922	86
07	5008	5094	5179	5265	5350	5436	5522	5607	5693	5778	86
08	5864	5949	6035	6120	6206	6291	6376	6462	6547	6632	85
09	6718	6803	6888	6974	7059	7144	7229	7315	7400	7485	85

N.	Diff.	1	2	3	4	5	6	7	8	9	Diff.
PROP. PARTS	94	9	19	28	38	47	56	66	75	85	94
	93	9	19	28	37	47	56	65	74	84	93
	92	9	18	28	37	46	55	64	74	83	92
	91	9	18	27	36	46	55	64	73	82	91
	90	9	18	27	36	45	54	63	72	81	90
	89	9	18	27	36	45	53	62	71	80	89
	88	9	18	26	35	44	53	62	70	79	88
	87	9	17	26	35	44	52	61	70	78	87
	86	9	17	26	34	43	52	60	69	77	86
	85	9	17	26	34	43	51	60	68	77	85
	Diff.	1	2	3	4	5	6	7	8	9	Diff.

N.	0	1	2	3	4	5	6	7	8	9	D
510	707570	7655	7740	7826	7911	7996	8081	8166	8251	8336	
511	8421	8506	8591	8676	8761	8846	8931	9015	9100	9185	
512	9270	9355	9440	9524	9609	9694	9779	9863	9948	*0033	
513	710117	0202	0287	0371	0456	0540	0625	0710	0794	0879	
514	0963	1048	1132	1217	1301	1385	1470	1554	1639	1723	
515	711807	1892	1976	2060	2144	2229	2313	2397	2481	2566	
516	2650	2734	2818	2902	2986	3070	3154	3238	3323	3407	
517	3491	3575	3659	3742	3826	3910	3994	4078	4162	4246	
518	4330	4414	4497	4581	4665	4749	4833	4916	5000	5084	
519	5167	5251	5335	5418	5502	5586	5669	5753	5836	5920	
520	716003	6087	6170	6254	6337	6421	6504	6588	6671	6754	
521	6838	6921	7004	7088	7171	7254	7338	7421	7504	7587	
522	7671	7754	7837	7920	8003	8086	8169	8253	8336	8419	
523	8502	8585	8668	8751	8834	8917	9000	9083	9165	9248	
524	9331	9414	9497	9580	9663	9745	9828	9911	9994	*0077	
525	720159	0242	0325	0407	0490	0573	0655	0738	0821	0903	
526	0986	1068	1151	1233	1316	1398	1481	1563	1646	1728	
527	1811	1893	1975	2058	2140	2222	2305	2387	2469	2552	
528	2634	2716	2798	2881	2963	3045	3127	3209	3291	3374	
529	3456	3538	3620	3702	3784	3866	3948	4030	4112	4194	
530	724276	4358	4440	4522	4604	4685	4767	4849	4931	5013	
531	5095	5176	5258	5340	5422	5503	5585	5667	5748	5830	
532	5912	5993	6075	6156	6238	6320	6401	6483	6564	6646	
533	6727	6809	6890	6972	7053	7134	7216	7297	7379	7460	
534	7541	7623	7704	7785	7866	7948	8029	8110	8191	8273	
535	728354	8435	8516	8597	8678	8759	8841	8922	9003	9084	
536	9165	9246	9327	9408	9489	9570	9651	9732	9813	9893	
537	9974	*0055	*0136	*0217	*0298	*0378	*0459	*0540	*0621	*0702	
538	730782	0863	0944	1024	1105	1186	1266	1347	1428	1508	
539	1589	1669	1750	1830	1911	1991	2072	2152	2233	2313	
540	732394	2474	2555	2635	2715	2796	2876	2956	3037	3117	
541	3197	3278	3358	3438	3518	3598	3679	3759	3839	3919	
542	3999	4079	4160	4240	4320	4400	4480	4560	4640	4720	
543	4800	4880	4960	5040	5120	5200	5279	5359	5439	5519	
544	5599	5679	5759	5838	5918	5998	6078	6157	6237	6317	
545	736397	6476	6556	6635	6715	6795	6874	6954	7034	7113	
546	7193	7272	7352	7431	7511	7590	7670	7749	7829	7908	
547	7987	8067	8146	8225	8305	8384	8463	8543	8622	8701	
548	8781	8860	8939	9018	9097	9177	9256	9335	9414	9493	
549	9572	9651	9731	9810	9889	9968	*0047	*0126	*0205	*0284	
550	740363	0442	0521	0600	0678	0757	0836	0915	0994	1073	
551	1152	1230	1309	1388	1467	1546	1624	1703	1782	1860	
552	1939	2018	2096	2175	2254	2332	2411	2489	2568	2647	
553	2725	2804	2882	2961	3039	3118	3196	3275	3353	3431	
554	3510	3588	3667	3745	3823	3902	3980	4058	4136	4215	

N.	Diff.	1	2	3	4	5	6	7	8	9	Di
PROP. PARTS	86	9	17	26	34	43	52	60	69	77	8
	85	9	17	26	34	43	51	60	68	77	8
	84	8	17	25	34	42	50	59	67	76	8
	83	8	17	25	33	42	50	58	66	75	8
	82	8	16	25	33	41	49	57	66	74	8
	81	8	16	24	32	41	49	57	65	73	8
	80	8	16	24	32	40	48	56	64	72	8
	79	8	16	24	32	40	47	55	63	71	7
	Diff.	1	2	3	4	5	6	7	8	9	Di

N.	0	1	2	3	4	5	6	7	8	9	Diff.
555	744293	4371	4449	4528	4606	4684	4762	4840	4919	4997	78
556	5075	5153	5231	5309	5387	5465	5543	5621	5699	5777	78
557	5855	5933	6011	6089	6167	6245	6323	6401	6479	6556	78
558	6634	6712	6790	6868	6945	7023	7101	7179	7256	7334	78
559	7412	7489	7567	7645	7722	7800	7878	7955	8033	8110	78
560	748188	8266	8343	8421	8498	8576	8653	8731	8808	8885	77
561	8963	9040	9118	9195	9272	9350	9427	9504	9582	9659	77
562	9736	9814	9891	9968	*0045	*0123	*0200	*0277	*0354	*0431	77
563	750508	0586	0663	0740	0817	0894	0971	1048	1125	1202	77
564	1279	1356	1433	1510	1587	1664	1741	1818	1895	1972	77
565	752048	2125	2202	2279	2356	2433	2509	2586	2663	2740	77
566	2816	2893	2970	3047	3123	3200	3277	3353	3430	3506	77
567	3583	3660	3736	3813	3889	3966	4042	4119	4195	4272	77
568	4348	4425	4501	4578	4654	4730	4807	4883	4960	5036	76
569	5112	5189	5265	5341	5417	5494	5570	5646	5722	5799	76
570	755875	5951	6027	6103	6180	6256	6332	6408	6484	6560	76
571	6636	6712	6788	6864	6940	7016	7092	7168	7244	7320	76
572	7396	7472	7548	7624	7700	7775	7851	7927	8003	8079	76
573	8155	8230	8306	8382	8458	8533	8609	8685	8761	8836	76
574	8912	8988	9063	9139	9214	9290	9366	9441	9517	9592	76
575	759668	9743	9819	9894	9970	*0045	*0121	*0196	*0272	*0347	75
576	760422	0498	0573	0649	0724	0799	0875	0950	1025	1101	75
577	1176	1251	1326	1402	1477	1552	1627	1702	1778	1853	75
578	1928	2003	2078	2153	2228	2303	2378	2453	2529	2604	75
579	2679	2754	2829	2904	2978	3053	3128	3203	3278	3353	75
580	763428	3503	3578	3653	3727	3802	3877	3952	4027	4101	75
581	4176	4251	4326	4400	4475	4550	4624	4699	4774	4848	75
582	4923	4998	5072	5147	5221	5296	5370	5445	5520	5594	75
583	5669	5743	5818	5892	5966	6041	6115	6190	6264	6338	74
584	6413	6487	6562	6636	6710	6785	6859	6933	7007	7082	74
585	767156	7230	7304	7379	7453	7527	7601	7675	7749	7823	74
586	7898	7972	8046	8120	8194	8268	8342	8416	8490	8564	74
587	8638	8712	8786	8860	8934	9008	9082	9156	9230	9303	74
588	9377	9451	9525	9599	9673	9746	9820	9894	9968	*0042	74
589	770115	0189	0263	0336	0410	0484	0557	0631	0705	0778	74
590	770852	0926	0999	1073	1146	1220	1293	1367	1440	1514	74
591	1587	1661	1734	1808	1881	1955	2028	2102	2175	2248	73
592	2322	2395	2468	2542	2615	2688	2762	2835	2908	2981	73
593	3055	3128	3201	3274	3348	3421	3494	3567	3640	3713	73
594	3786	3860	3933	4006	4079	4152	4225	4298	4371	4444	73
595	774517	4590	4663	4736	4809	4882	4955	5028	5100	5173	73
596	5246	5319	5392	5465	5538	5610	5683	5756	5829	5902	73
597	5974	6047	6120	6193	6265	6338	6411	6483	6556	6629	73
598	6701	6774	6846	6919	6992	7064	7137	7209	7282	7354	73
599	7427	7499	7572	7644	7717	7789	7862	7934	8006	8079	72

N.	Diff.	1	2	3	4	5	6	7	8	9	Diff.
PRO. PARTS	78	8	16	23	31	39	47	55	62	70	78
	77	8	15	23	31	39	46	54	62	69	77
	76	8	15	23	30	38	46	53	61	68	76
	75	8	15	23	30	38	45	53	60	68	75
	74	7	15	22	30	37	44	52	59	67	74
	73	7	15	22	29	37	44	51	58	66	73
	72	7	14	22	29	36	43	50	58	65	72
	Diff.	1	2	3	4	5	6	7	8	9	Diff.

N.	0	1	2	3	4	5	6	7	8	9	Diff.
600	778151	8224	8296	8368	8441	8513	8585	8658	8730	8802	72
601	8874	8947	9019	9091	9163	9236	9308	9380	9452	9524	72
602	9596	9669	9741	9813	9885	9957	*0029	*0101	*0173	*0245	72
603	780317	0389	0461	0533	0605	0677	0749	0821	0893	0965	72
604	1037	1109	1181	1253	1324	1396	1468	1540	1612	1684	72
605	781755	1827	1899	1971	2042	2114	2186	2258	2329	2401	72
606	2473	2544	2616	2688	2759	2831	2902	2974	3046	3117	72
607	3189	3260	3332	3403	3475	3546	3618	3689	3761	3832	71
608	3904	3975	4046	4118	4189	4261	4332	4403	4475	4546	71
609	4617	4689	4760	4831	4902	4974	5045	5116	5187	5259	71
610	785330	5401	5472	5543	5615	5686	5757	5828	5899	5970	71
611	6041	6112	6183	6254	6325	6396	6467	6538	6609	6680	71
612	6751	6822	6893	6964	7035	7106	7177	7248	7319	7390	71
613	7460	7531	7602	7673	7744	7815	7885	7956	8027	8098	71
614	8168	8239	8310	8381	8451	8522	8593	8663	8734	8804	71
615	788875	8946	9016	9087	9157	9228	9299	9369	9440	9510	71
616	9581	9651	9722	9792	9863	9933	*0004	*0074	*0144	*0215	70
617	790285	0356	0426	0496	0567	0637	0707	0778	0848	0918	70
618	0988	1059	1129	1199	1269	1340	1410	1480	1550	1620	70
619	1691	1761	1831	1901	1971	2041	2111	2181	2252	2322	70
620	792392	2462	2532	2602	2672	2742	2812	2882	2952	3022	70
621	3092	3162	3231	3301	3371	3441	3511	3581	3651	3721	70
622	3790	3860	3930	4000	4070	4139	4209	4279	4349	4418	70
623	4488	4558	4627	4697	4767	4836	4906	4976	5045	5115	70
624	5185	5254	5324	5393	5463	5532	5602	5672	5741	5811	70
625	795880	5949	6019	6088	6158	6227	6297	6366	6436	6505	69
626	6574	6644	6713	6782	6852	6921	6990	7060	7129	7198	69
627	7268	7337	7406	7475	7545	7614	7683	7752	7821	7890	69
628	7960	8029	8098	8167	8236	8305	8374	8443	8513	8582	69
629	8651	8720	8789	8858	8927	8996	9065	9134	9203	9272	69
630	799341	9409	9478	9547	9616	9685	9754	9823	9892	9961	69
631	800029	0098	0167	0236	0305	0373	0442	0511	0580	0648	69
632	0717	0786	0854	0923	0992	1061	1129	1198	1266	1335	69
633	1404	1472	1541	1609	1678	1747	1815	1884	1952	2021	69
634	2089	2158	2226	2295	2363	2432	2500	2568	2637	2705	68
635	802774	2842	2910	2979	3047	3116	3184	3252	3321	3389	68
636	3457	3525	3594	3662	3730	3798	3867	3935	4003	4071	68
637	4139	4208	4276	4344	4412	4480	4548	4616	4685	4753	68
638	4821	4889	4957	5025	5093	5161	5229	5297	5365	5433	68
639	5501	5569	5637	5705	5773	5841	5908	5976	6044	6112	68
640	806180	6248	6316	6384	6451	6519	6587	6655	6723	6790	68
641	6858	6926	6994	7061	7129	7197	7264	7332	7400	7467	68
642	7535	7603	7670	7738	7806	7873	7941	8008	8076	8143	68
643	8211	8279	8346	8414	8481	8549	8616	8684	8751	8818	67
644	8886	8953	9021	9088	9156	9223	9290	9358	9425	9492	67
645	809560	9627	9694	9762	9829	9896	9964	*0031	*0098	*0165	67
646	810233	0300	0367	0434	0501	0569	0636	0703	0770	0837	67
647	0904	0971	1039	1106	1173	1240	1307	1374	1441	1508	67
648	1575	1642	1709	1776	1843	1910	1977	2044	2111	2178	67
649	2245	2312	2379	2445	2512	2579	2646	2713	2780	2847	67

N.	Diff.	1	2	3	4	5	6	7	8	9	Diff.
PRO. P'TS	73	7	15	22	29	37	44	51	58	66	73
	72	7	14	22	29	36	43	50	58	65	72
	71	7	14	21	28	36	43	50	57	64	71
	70	7	14	21	28	35	42	49	56	63	70
	69	7	14	21	28	35	41	48	55	62	69
	68	7	14	20	27	34	41	48	54	61	68
	Diff.	1	2	3	4	5	6	7	8	9	Diff.

N.	0	1	2	3	4	5	6	7	8	9	Diff.
650	812913	2980	3047	3114	3181	3247	3314	3381	3448	3514	67
651	3581	3648	3714	3781	3848	3914	3981	4048	4114	4181	67
652	4248	4314	4381	4447	4514	4581	4647	4714	4780	4847	67
653	4913	4980	5046	5113	5179	5246	5312	5378	5445	5511	66
654	5578	5644	5711	5777	5843	5910	5976	6042	6109	6175	66
655	816241	6308	6374	6440	6506	6573	6639	6705	6771	6838	66
656	6904	6970	7036	7102	7169	7235	7301	7367	7433	7499	66
657	7565	7631	7698	7764	7830	7896	7962	8028	8094	8160	66
658	8226	8292	8358	8424	8490	8556	8622	8688	8754	8820	66
659	8885	8951	9017	9083	9149	9215	9281	9346	9412	9478	66
660	819544	9610	9676	9741	9807	9873	9939	*0004	*0070	*0136	66
661	820201	0267	0333	0399	0464	0530	0595	0661	0727	0792	66
662	0858	0924	0989	1055	1120	1186	1251	1317	1382	1448	66
663	1514	1579	1645	1710	1775	1841	1906	1972	2037	2103	65
664	2168	2233	2299	2364	2430	2495	2560	2626	2691	2756	65
665	822822	2887	2952	3018	3083	3148	3213	3279	3344	3409	65
666	3474	3539	3605	3670	3735	3800	3865	3930	3996	4061	65
667	4126	4191	4256	4321	4386	4451	4516	4581	4646	4711	65
668	4776	4841	4906	4971	5036	5101	5166	5231	5296	5361	65
669	5426	5491	5556	5621	5686	5751	5815	5880	5945	6010	65
670	826075	6140	6204	6269	6334	6399	6464	6528	6593	6658	65
671	6723	6787	6852	6917	6981	7046	7111	7175	7240	7305	65
672	7369	7434	7499	7563	7628	7692	7757	7821	7886	7951	65
673	8015	8080	8144	8209	8273	8338	8402	8467	8531	8595	64
674	8660	8724	8789	8853	8918	8982	9046	9111	9175	9239	64
675	829304	9368	9432	9497	9561	9625	9690	9754	9818	9882	64
676	9947	*0011	*0075	*0139	*0204	*0268	*0332	*0396	*0460	*0525	64
677	830589	0653	0717	0781	0845	0909	0973	1037	1102	1166	64
678	1230	1294	1358	1422	1486	1550	1614	1678	1742	1806	64
679	1870	1934	1998	2062	2126	2189	2253	2317	2381	2445	64
680	832509	2573	2637	2700	2764	2828	2892	2956	3020	3083	64
681	3147	3211	3275	3338	3402	3466	3530	3593	3657	3721	64
682	3784	3848	3912	3975	4039	4103	4166	4230	4294	4357	64
683	4421	4484	4548	4611	4675	4739	4802	4866	4929	4993	64
684	5056	5120	5183	5247	5310	5373	5437	5500	5564	5627	63
685	835691	5754	5817	5881	5944	6007	6071	6134	6197	6261	63
686	6324	6387	6451	6514	6577	6641	6704	6767	6830	6894	63
687	6957	7020	7083	7146	7210	7273	7336	7399	7462	7525	63
688	7588	7652	7715	7778	7841	7904	7967	8030	8093	8156	63
689	8219	8282	8345	8408	8471	8534	8597	8660	8723	8786	63
690	838849	8912	8975	9038	9101	9164	9227	9289	9352	9415	63
691	9478	9541	9604	9667	9729	9792	9855	9918	9981	*0043	63
692	840106	0169	0232	0294	0357	0420	0482	0545	0608	0671	63
693	0733	0796	0859	0921	0984	1046	1109	1172	1234	1297	63
694	1359	1422	1485	1547	1610	1672	1735	1797	1860	1922	63
695	841985	2047	2110	2172	2235	2297	2360	2422	2484	2547	62
696	2609	2672	2734	2796	2859	2921	2983	3046	3108	3170	62
697	3233	3295	3357	3420	3482	3544	3606	3669	3731	3793	62
698	3855	3918	3980	4042	4104	4166	4229	4291	4353	4415	62
699	4477	4539	4601	4664	4726	4788	4850	4912	4974	5036	62

N.	Diff.	1	2	3	4	5	6	7	8	9	Diff.
PRO. P'TS	67	7	13	20	27	34	40	47	54	60	67
	66	7	13	20	26	33	40	46	53	59	66
	65	7	13	20	26	33	39	46	52	59	65
	64	6	13	19	26	32	38	45	51	58	64
	63	6	13	19	25	32	38	44	50	57	63
	62	6	12	19	25	31	37	43	50	56	62
	Diff.	1	2	3	4	5	6	7	8	9	Diff.

N.	0	1	2	3	4	5	6	7	8	9	Dif
700	845098	5160	5222	5284	5346	5408	5470	5532	5594	5656	62
701	5718	5780	5842	5904	5966	6028	6090	6151	6213	6275	62
702	6337	6399	6461	6523	6585	6646	6708	6770	6832	6894	62
703	6955	7017	7079	7141	7202	7264	7326	7388	7449	7511	62
704	7573	7634	7696	7758	7819	7881	7943	8004	8066	8128	62
705	848189	8251	8312	8374	8435	8497	8559	8620	8682	8743	62
706	8805	8866	8928	8989	9051	9112	9174	9235	9297	9358	61
707	9419	9481	9542	9604	9665	9726	9788	9849	9911	9972	61
708	850033	0095	0156	0217	0279	0340	0401	0462	0524	0585	61
709	0646	0707	0769	0830	0891	0952	1014	1075	1136	1197	61
710	851258	1320	1381	1442	1503	1564	1625	1686	1747	1809	61
711	1870	1931	1992	2053	2114	2175	2236	2297	2358	2419	61
712	2480	2541	2602	2663	2724	2785	2846	2907	2968	3029	61
713	3090	3150	3211	3272	3333	3394	3455	3516	3577	3637	61
714	3698	3759	3820	3881	3941	4002	4063	4124	4185	4245	61
715	854306	4367	4428	4488	4549	4610	4670	4731	4792	4852	61
716	4913	4974	5034	5095	5156	5216	5277	5337	5398	5459	61
717	5519	5580	5640	5701	5761	5822	5882	5943	6003	6064	61
718	6124	6185	6245	6306	6366	6427	6487	6548	6608	6668	60
719	6729	6789	6850	6910	6970	7031	7091	7152	7212	7272	60
720	857332	7393	7453	7513	7574	7634	7694	7755	7815	7875	60
721	7935	7995	8056	8116	8176	8236	8297	8357	8417	8477	60
722	8537	8597	8657	8718	8778	8838	8898	8958	9018	9078	60
723	9138	9198	9258	9318	9379	9439	9499	9559	9619	9679	60
724	9739	9799	9859	9918	9978	*0038	*0098	*0158	*0218	*0278	60
725	860338	0398	0458	0518	0578	0637	0697	0757	0817	0877	60
726	0937	0996	1056	1116	1176	1236	1295	1355	1415	1475	60
727	1534	1594	1654	1714	1773	1833	1893	1952	2012	2072	60
728	2131	2191	2251	2310	2370	2430	2489	2549	2608	2668	60
729	2728	2787	2847	2906	2966	3025	3085	3144	3204	3263	60
730	863323	3382	3442	3501	3561	3620	3680	3739	3799	3858	59
731	3917	3977	4036	4096	4155	4214	4274	4333	4392	4452	59
732	4511	4570	4630	4689	4748	4808	4867	4926	4985	5045	59
733	5104	5163	5222	5282	5341	5400	5459	5519	5578	5637	59
734	5696	5755	5814	5874	5933	5992	6051	6110	6169	6228	59
735	866287	6346	6405	6465	6524	6583	6642	6701	6760	6819	59
736	6878	6937	6996	7055	7114	7173	7232	7291	7350	7409	59
737	7467	7526	7585	7644	7703	7762	7821	7880	7939	7998	59
738	8056	8115	8174	8233	8292	8350	8409	8468	8527	8586	59
739	8644	8703	8762	8821	8879	8938	8997	9056	9114	9173	59
740	869232	9290	9349	9408	9466	9525	9584	9642	9701	9760	59
741	9818	9877	9935	9994	*0053	*0111	*0170	*0228	*0287	*0345	59
742	870404	0462	0521	0579	0638	0696	0755	0813	0872	0930	58
743	0989	1047	1106	1164	1223	1281	1339	1398	1456	1515	58
744	1573	1631	1690	1748	1806	1865	1923	1981	2040	2098	58
745	872156	2215	2273	2331	2389	2448	2506	2564	2622	2681	58
746	2739	2797	2855	2913	2972	3030	3088	3146	3204	3262	58
747	3321	3379	3437	3495	3553	3611	3669	3727	3785	3844	58
748	3902	3960	4018	4076	4134	4192	4250	4308	4366	4424	58
749	4482	4540	4598	4656	4714	4772	4830	4888	4945	5003	58

N.	Diff.	1	2	3	4	5	6	7	8	9	Dif
PRO. P'TS	62	6	12	19	25	31	37	43	50	56	62
	61	6	12	18	24	31	37	43	49	55	61
	60	6	12	18	24	30	36	42	48	54	60
	59	6	12	18	24	30	35	41	47	53	59
	58	6	12	17	23	29	35	41	46	52	58
	Diff.	1	2	3	4	5	6	7	8	9	Dif

N.	0	1	2	3	4	5	6	7	8	9	Diff.
50	875061	5119	5177	5235	5293	5351	5409	5466	5524	5582	58
51	5640	5698	5756	5813	5871	5929	5987	6045	6102	6160	58
52	6218	6276	6333	6391	6449	6507	6564	6622	6680	6737	58
53	6795	6853	6910	6968	7026	7083	7141	7199	7256	7314	58
54	7371	7429	7487	7544	7602	7659	7717	7774	7832	7889	58
55	877947	8004	8062	8119	8177	8234	8292	8349	8407	8464	57
56	8522	8579	8637	8694	8752	8809	8866	8924	8981	9039	57
57	9096	9153	9211	9268	9325	9383	9440	9497	9555	9612	57
58	9669	9726	9784	9841	9898	9956	*0013	*0070	*0127	*0185	57
59	880242	0299	0356	0413	0471	0528	0585	0642	0699	0756	57
60	880814	0871	0928	0985	1042	1099	1156	1213	1271	1328	57
61	1385	1442	1499	1556	1613	1670	1727	1784	1841	1898	57
62	1955	2012	2069	2126	2183	2240	2297	2354	2411	2468	57
63	2525	2581	2638	2695	2752	2809	2866	2923	2980	3037	57
64	3093	3150	3207	3264	3321	3377	3434	3491	3548	3605	57
65	883661	3718	3775	3832	3888	3945	4002	4059	4115	4172	57
66	4229	4285	4342	4399	4455	4512	4569	4625	4682	4739	57
67	4795	4852	4909	4965	5022	5078	5135	5192	5248	5305	57
68	5361	5418	5474	5531	5587	5644	5700	5757	5813	5870	57
69	5926	5983	6039	6096	6152	6209	6265	6321	6378	6434	56
70	886491	6547	6604	6660	6716	6773	6829	6885	6942	6998	56
71	7054	7111	7167	7223	7280	7336	7392	7449	7505	7561	56
72	7617	7674	7730	7786	7842	7898	7955	8011	8067	8123	56
73	8179	8236	8292	8348	8404	8460	8516	8573	8629	8685	56
74	8741	8797	8853	8909	8965	9021	9077	9134	9190	9246	56
75	889302	9358	9414	9470	9526	9582	9638	9694	9750	9806	56
76	9862	9918	9974	*0030	*0086	*0141	*0197	*0253	*0309	*0365	56
77	890421	0477	0533	0589	0645	0700	0756	0812	0868	0924	56
78	0980	1035	1091	1147	1203	1259	1314	1370	1426	1482	56
79	1537	1593	1649	1705	1760	1816	1872	1928	1983	2039	56
80	892095	2150	2206	2262	2317	2373	2429	2484	2540	2595	56
81	2651	2707	2762	2818	2873	2929	2985	3040	3096	3151	56
82	3207	3262	3318	3373	3429	3484	3540	3595	3651	3706	56
83	3762	3817	3873	3928	3984	4039	4094	4150	4205	4261	55
84	4316	4371	4427	4482	4538	4593	4648	4704	4759	4814	55
85	894870	4925	4980	5036	5091	5146	5201	5257	5312	5367	55
86	5423	5478	5533	5588	5644	5699	5754	5809	5864	5920	55
87	5975	6030	6085	6140	6195	6251	6306	6361	6416	6471	55
88	6526	6581	6636	6692	6747	6802	6857	6912	6967	7022	55
89	7077	7132	7187	7242	7297	7352	7407	7462	7517	7572	55
90	897627	7682	7737	7792	7847	7902	7957	8012	8067	8122	55
91	8176	8231	8286	8341	8396	8451	8506	8561	8615	8670	55
92	8725	8780	8835	8890	8944	8999	9054	9109	9164	9218	55
93	9273	9328	9383	9437	9492	9547	9602	9656	9711	9766	55
94	9821	9875	9930	9985	*0039	*0094	*0149	*0203	*0258	*0312	55
95	900367	0422	0476	0531	0586	0640	0695	0749	0804	0859	55
96	0913	0968	1022	1077	1131	1186	1240	1295	1349	1404	55
97	1458	1513	1567	1622	1676	1731	1785	1840	1894	1948	54
98	2003	2057	2112	2166	2221	2275	2329	2384	2438	2492	54
99	2547	2601	2655	2710	2764	2818	2873	2927	2981	3036	54

N.	Diff.	1	2	3	4	5	6	7	8	9	Diff.
PR. PTS.	57	6	11	17	23	29	34	40	46	51	57
	56	6	11	17	22	28	34	39	45	50	56
	55	6	11	17	22	28	33	39	44	50	55
	54	5	11	16	22	27	32	38	43	49	54
	Diff.	1	2	3	4	5	6	7	8	9	Diff.

N.	0	1	2	3	4	5	6	7	8	9	Diff.
800	903090	3144	3199	3253	3307	3361	3416	3470	3524	3578	54
801	3633	3687	3741	3795	3849	3904	3958	4012	4066	4120	54
802	4174	4229	4283	4337	4391	4445	4499	4553	4607	4661	54
803	4716	4770	4824	4878	4932	4986	5040	5094	5148	5202	54
804	5256	5310	5364	5418	5472	5526	5580	5634	5688	5742	54
805	905796	5850	5904	5958	6012	6066	6119	6173	6227	6281	54
806	6335	6389	6443	6497	6551	6604	6658	6712	6766	6820	54
807	6874	6927	6981	7035	7089	7143	7196	7250	7304	7358	54
808	7411	7465	7519	7573	7626	7680	7734	7787	7841	7895	54
809	7949	8002	8056	8110	8163	8217	8270	8324	8378	8431	54
810	908485	8539	8592	8646	8699	8753	8807	8860	8914	8967	54
811	9021	9074	9128	9181	9235	9289	9342	9396	9449	9503	54
812	9556	9610	9663	9716	9770	9823	9877	9930	9984	*0037	53
813	910091	0144	0197	0251	0304	0358	0411	0464	0518	0571	53
814	0624	0678	0731	0784	0838	0891	0944	0998	1051	1104	53
815	911158	1211	1264	1317	1371	1424	1477	1530	1584	1637	53
816	1690	1743	1797	1850	1903	1956	2009	2063	2116	2169	53
817	2222	2275	2328	2381	2435	2488	2541	2594	2647	2700	53
818	2753	2806	2859	2913	2966	3019	3072	3125	3178	3231	53
819	3284	3337	3390	3443	3496	3549	3602	3655	3708	3761	53
820	913814	3867	3920	3973	4026	4079	4132	4184	4237	4290	53
821	4343	4396	4449	4502	4555	4608	4660	4713	4766	4819	53
822	4872	4925	4977	5030	5083	5136	5189	5241	5294	5347	53
823	5400	5453	5505	5558	5611	5664	5716	5769	5822	5875	53
824	5927	5980	6033	6085	6138	6191	6243	6296	6349	6401	53
825	916454	6507	6559	6612	6664	6717	6770	6822	6875	6927	53
826	6980	7033	7085	7138	7190	7243	7295	7348	7400	7453	53
827	7506	7558	7611	7663	7716	7768	7820	7873	7925	7978	52
828	8030	8083	8135	8188	8240	8293	8345	8397	8450	8502	52
829	8555	8607	8659	8712	8764	8816	8869	8921	8973	9026	52
830	919078	9130	9183	9235	9287	9340	9392	9444	9496	9549	52
831	9601	9653	9706	9758	9810	9862	9914	9967	*0019	*0071	52
832	920123	0176	0228	0280	0332	0384	0436	0489	0541	0593	52
833	0645	0697	0749	0801	0853	0906	0958	1010	1062	1114	52
834	1166	1218	1270	1322	1374	1426	1478	1530	1582	1634	52
835	921686	1738	1790	1842	1894	1946	1998	2050	2102	2154	52
836	2206	2258	2310	2362	2414	2466	2518	2570	2622	2674	52
837	2725	2777	2829	2881	2933	2985	3037	3089	3140	3192	52
838	3244	3296	3348	3399	3451	3503	3555	3607	3658	3710	52
839	3762	3814	3865	3917	3969	4021	4072	4124	4176	4228	52
840	924279	4331	4383	4434	4486	4538	4589	4641	4693	4744	52
841	4796	4848	4899	4951	5003	5054	5106	5157	5209	5261	52
842	5312	5364	5415	5467	5518	5570	5621	5673	5725	5776	52
843	5828	5879	5931	5982	6034	6085	6137	6188	6240	6291	51
844	6342	6394	6445	6497	6548	6600	6651	6702	6754	6805	51
845	926857	6908	6959	7011	7062	7114	7165	7216	7268	7319	51
846	7370	7422	7473	7524	7576	7627	7678	7730	7781	7832	51
847	7883	7935	7986	8037	8088	8140	8191	8242	8293	8345	51
848	8396	8447	8498	8549	8601	8652	8703	8754	8805	8857	51
849	8908	8959	9010	9061	9112	9163	9215	9266	9317	9368	51

N.	Diff.	1	2	3	4	5	6	7	8	9	Diff
PR. PTS.	55	6	11	17	22	28	33	39	44	50	55
	54	5	11	16	22	27	32	38	43	49	54
	53	5	11	16	21	27	32	37	42	48	53
	52	5	10	16	21	26	31	36	42	47	52
	Diff.	1	2	3	4	5	6	7	8	9	Diff

N	0	1	2	3	4	5	6	7	8	9	Diff.
	929419	9470	9521								
	9930	9981	*00[illegible]								
	930440	0491	[illegible]								
	0949	1000									
	1458	1509									
	931966	2017									
	2474	2524									
	2981	303									
	3487	35[illegible]									
	3993	4[illegible]									
	934498										
	5003										
	5507										
	6011										
	6514										
	93701[illegible]										
	751										
	801										
	85[illegible]										
	90[illegible]										
	9395										
	940[illegible]										
82											
83	59[illegible]										
84	6452										
85	46943	69[illegible]									
86	7434	7483									
87	7924	7973	[illegible]								
88	8413	8462	851[illegible]		[illegible]09		8706	87[illegible]			
89	8902	8951	8999		9097	9146	9195	9244	9[illegible]		
90	9390	9439	9488	95[illegible]	9585	9634	9683	9731	9780		
91	9878	9926	9975	*0024	*0073	*0121	*0170	*0219	*0267		
92	[illegible]365	0414	0462	0511	0560	0608	0657	0706	0754	[illegible]	
93	[illegible]851	0900	0949	0997	1046	1095	1143	1192	1240	1289	
94	[illegible]338	1386	1435	1483	1532	1580	1629	1677	1726	1775	
95	[illegible]823	1872	1920	1969	2017	2066	2114	2163	2211	2260	
96	[illegible]308	2356	2405	2453	2502	2550	2599	2647	2696	2744	
97	[illegible]792	2841	2889	2938	2986	3034	3083	3131	3180	3228	
98	[illegible]276	3325	3373	3421	3470	3518	3566	3615	3663	3711	
99	[illegible]760	3808	3856	3905	3953	4001	4049	4098	4146	4194	4[illegible] 48

Diff.	1	2	3	4	5	6	7	8	9	Diff.
51	5	10	15	20	26	31	36	41	46	51
50	5	10	15	20	25	30	35	40	45	50
49	5	10	15	20	25	29	34	39	44	49
48	5	10	14	19	24	29	34	38	43	48
	1	2	3	4	5	6	7	8	9	Diff.

7	8	9
4580	4628	4677
62	5110	5158
3	5592	5640
	6072	6120
	6553	6601
	7032	7080
	7512	7559
	7990	8038
	468	8516
	46	8994
		9471
		9947
		*0423
		0899
		1374
		1848
		2322
		2795
		3268
		741
		4212
		684
		5

N.	Diff.	1	2	3	4	5	6	7	8
									3
									1647
									2110
								7	2573
			758	2804	28	2897		2989	3035
		3174	3220	3266	3313	3359	34	3451	3497
		3636	3682	3728	3774	3820	3866	3913	3959
	1	4097	4143	4189	4235	4281	4327	4374	4420
	512	4558	4604	4650	4696	4742	4788	4834	4880
	4972	5018	5064	5110	5156	5202	5248	5294	5340
	975432	5478	5524	5570	5616	5662	5707	5753	5799
	5891	5937	5983	6029	6075	6121	6167	6212	6258
	6350	6396	6442	6488	6533	6579	6625	6671	6717
	6808	6854	6900	6946	6992	7037	7083	7129	7175
49	7266	7312	7358	7403	7449	7495	7541	7586	7632

PR. PTS.	Diff.	1	2	3	4	5	6	7	8
	49	5	10	15	20	25	29	34	39
	48	5	10	14	19	24	29	34	38
	47	5	9	14	19	24	28	33	38
	46	5	9	14	18	23	28	32	37

N.	0	1	2	3	4	5	6	7	8	9	Diff.
950	977724	7769	7815	7861	7906	7952	7998	8043	8089	8135	46
951	8181	8226	8272	8317	8363	8409	8454	8500	8546	8591	46
952	8637	8683	8728	8774	8819	8865	8911	8956	9002	9047	46
953	9093	9138	9184	9230	'275	9321	9366	9412	9457	9503	46
954	9548	9594	9639	9685	9730	9776	9821	9867	9912	9958	46
955	980003	0049	0094	0140	0185	0231	0276	0322	0367	0412	45
956	0458	0503	0549	0594	0640	0685	0730	0776	0821	0867	45
957	0912	0957	1003	1048	1093	1139	1184	1229	1275	1320	45
958	1366	1411	1456	1501	1547	1592	1637	1683	1728	1773	45
959	1819	1864	1909	1954	2000	2045	2090	2135	2181	2226	45
960	982271	2316	2362	2407	2452	2497	2543	2588	2633	2678	45
961	2723	2769	2814	2859	2904	2949	2994	3040	3085	3130	45
962	3175	3220	3265	3310	3356	3401	3446	3491	3536	3581	45
963	3626	3671	3716	3762	3807	3852	3897	3942	3987	4032	45
964	4077	4122	4167	4212	4257	4302	4347	4392	4437	4482	45
965	984527	4572	4617	4662	4707	4752	4797	4842	4887	4932	45
966	4977	5022	5067	5112	5157	5202	5247	5292	5337	5382	45
967	5426	5471	5516	5561	5606	5651	5696	5741	5786	5830	45
968	5875	5920	5965	6010	6055	6100	6144	6189	6234	6279	45
969	6324	6369	6413	6458	6503	6548	6593	6637	6682	6727	45
970	986772	6817	6861	6906	6951	6996	7040	7085	7130	7175	45
971	7219	7264	7309	7353	7398	7443	7488	7532	7577	7622	45
972	7666	7711	7756	7800	7845	7890	7934	7979	8024	8068	45
973	8113	8157	8202	8247	8291	8336	8381	8425	8470	8514	45
974	8559	8604	8648	8693	8737	8782	8826	8871	8916	8960	45
975	989005	9049	9094	9138	9183	9227	9272	9316	9361	9405	45
976	9450	9494	9539	9583	9628	9672	9717	9761	9806	9850	44
977	9895	9939	9983	*0028	*0072	*0117	*0161	*0206	*0250	*0294	44
978	990339	0383	0428	0472	0516	0561	0605	0650	0694	0738	44
979	0783	0827	0871	0916	0960	1004	1049	1093	1137	1182	44
980	991226	1270	1315	1359	1403	1448	1492	1536	1580	1625	44
981	1669	1713	1758	1802	1846	1890	1935	1979	2023	2067	44
982	2111	2156	2200	2244	2288	2333	2377	2421	2465	2509	44
983	2554	2598	2642	2686	2730	2774	2819	2863	2907	2951	44
984	2995	3039	3083	3127	3172	3216	3260	3304	3348	3392	44
985	993436	3480	3524	3568	3613	3657	3701	3745	3789	3833	44
986	3877	3921	3965	4009	4053	4097	4141	4185	4229	4273	44
987	4317	4361	4405	4449	4493	4537	4581	4625	4669	4713	44
988	4757	4801	4845	4889	4933	4977	5021	5065	5108	5152	44
989	5196	5240	5284	5328	5372	5416	5460	5504	5547	5591	44
990	995635	5679	5723	5767	5811	5854	5898	5942	5986	6030	44
991	6074	6117	6161	6205	6249	6293	6337	6380	6424	6468	44
992	6512	6555	6599	6643	6687	6731	6774	6818	6862	6906	44
993	6949	6993	7037	7080	7124	7168	7212	7255	7299	7343	44
994	7386	7430	7474	7517	7561	7605	7648	7692	7736	7779	44
995	997823	7867	7910	7954	7998	8041	8085	8129	8172	8216	44
996	8259	8303	8347	8390	8434	8477	8521	8564	8608	8652	44
997	8695	8739	8782	8826	8869	8913	8956	9000	9043	9087	44
998	9131	9174	9218	9261	9305	9348	9392	9435	9479	9522	44
999	9565	9609	9652	9696	9739	9783	9826	9870	9913	9957	43

N.	Diff.	1	2	3	4	5	6	7	8	9	Diff.
PR. PTS.	46	5	9	14	18	23	28	32	37	41	46
	45	5	9	14	18	23	27	32	36	41	45
	44	4	9	13	18	22	26	31	35	40	44
	43	4	9	13	17	22	26	30	34	39	43
	Diff.	1	2	3	4	5	6	7	8	9	Diff.

N.	0	1	2	3	4	5	6	7	8	9	Diff.
1000	000000	0043	0087	0130	0174	0217	0260	0304	0347	0391	43
1001	0434	0477	0521	0564	0608	0651	0694	0738	0781	0824	43
1002	0868	0911	0954	0998	1041	1084	1128	1171	1214	1258	43
1003	1301	1344	1388	1431	1474	1517	1561	1604	1647	1690	43
1004	1734	1777	1820	1863	1907	1950	1993	2036	2080	2123	43
1005	002166	2209	2252	2296	2339	2382	2425	2468	2512	2555	43
1006	2598	2641	2684	2727	2771	2814	2857	2900	2943	2986	43
1007	3029	3073	3116	3159	3202	3245	3288	3331	3374	3417	43
1008	3461	3504	3547	3590	3633	3676	3719	3762	3805	3848	43
1009	3891	3934	3977	4020	4063	4106	4149	4192	4235	4278	43
1010	004321	4364	4407	4450	4493	4536	4579	4622	4665	4708	43
1011	4751	4794	4837	4880	4923	4966	5009	5052	5095	5138	43
1012	5181	5223	5266	5309	5352	5395	5438	5481	5524	5567	43
1013	5609	5652	5695	5738	5781	5824	5867	5909	5952	5995	43
1014	6038	6081	6124	6166	6209	6252	6295	6338	6380	6423	43
1015	006466	6509	6552	6594	6637	6680	6723	6765	6808	6851	43
1016	6894	6936	6979	7022	7065	7107	7150	7193	7236	7278	43
1017	7321	7364	7406	7449	7492	7534	7577	7620	7662	7705	43
1018	7748	7790	7833	7876	7918	7961	8004	8046	8089	8132	43
1019	8174	8217	8259	8302	8345	8387	8430	8472	8515	8558	43
1020	008600	8643	8685	8728	8770	8813	8856	8898	8941	8983	43
1021	9026	9068	9111	9153	9196	9238	9281	9323	9366	9408	42
1022	9451	9493	9536	9578	9621	9663	9706	9748	9791	9833	42
1023	9876	9918	9961	*0003	*0045	*0088	*0130	*0173	*0215	*0258	42
1024	010300	0342	0385	0427	0470	0512	0554	0597	0639	0681	42
1025	010724	0766	0809	0851	0893	0936	0978	1020	1063	1105	42
1026	1147	1190	1232	1274	1317	1359	1401	1444	1486	1528	42
1027	1570	1613	1655	1697	1740	1782	1824	1866	1909	1951	42
1028	1993	2035	2078	2120	2162	2204	2247	2289	2331	2373	42
1029	2415	2458	2500	2542	2584	2626	2669	2711	2753	2795	42
1030	012837	2879	2922	2964	3006	3048	3090	3132	3174	3217	42
1031	3259	3301	3343	3385	3427	3469	3511	3553	3596	3638	42
1032	3680	3722	3764	3806	3848	3890	3932	3974	4016	4058	42
1033	4100	4142	4184	4226	4268	4310	4353	4395	4437	4479	42
1034	4521	4563	4605	4647	4689	4730	4772	4814	4856	4898	42
1035	014940	4982	5024	5066	5108	5150	5192	5234	5276	5318	42
1036	5360	5402	5444	5485	5527	5569	5611	5653	5695	5737	42
1037	5779	5821	5863	5904	5946	5988	6030	6072	6114	6156	42
1038	6197	6239	6281	6323	6365	6407	6448	6490	6532	6574	42
1039	6616	6657	6699	6741	6783	6824	6866	6908	6950	6992	42
1040	017033	7075	7117	7159	7200	7242	7284	7326	7367	7409	42
1041	7451	7492	7534	7576	7618	7659	7701	7743	7784	7826	42
1042	7868	7909	7951	7993	8034	8076	8118	8159	8201	8243	42
1043	8284	8326	8368	8409	8451	8492	8534	8576	8617	8659	42
1044	8700	8742	8784	8825	8867	8908	8950	8992	9033	9075	42
1045	019116	9158	9199	9241	9282	9324	9366	9407	9449	9490	42
1046	9532	9573	9615	9656	9698	9739	9781	9822	9864	9905	41
1047	9947	9988	*0030	*0071	*0113	*0154	*0195	*0237	*0278	*0320	41
1048	020361	0403	0444	0486	0527	0568	0610	0651	0693	0734	41
1049	0775	0817	0858	0900	0941	0982	1024	1065	1107	1148	41
1050	021189	1231	1272	1313	1355	1396	1437	1479	1520	1561	41
N.	0	1	2	3	4	5	6	7	8	9	Diff.

N.	Diff.	1	2	3	4	5	6	7	8	9	Diff.
PR.PTS.	44	4	9	13	18	22	26	31	35	40	44
	43	4	9	13	17	22	26	30	34	39	43
	42	4	8	13	17	21	25	29	34	38	42
	41	4	8	12	16	21	25	29	33	37	41
	Diff.	1	2	3	4	5	6	7	8	9	Diff.

0° | TABLE OF LOGARITHMIC SINES—COSINES | 179°

M.	Sin.	D. 1″.	Cos.	D. 1″.	Tan.	D. 1″.	Cot.	
0	—∞		10.000000		—∞		—∞	60
1	6.463726	5017.17	.000000	.00	6.463726	5017.17	3.536274	59
2	.764756	2934.85	.000000	.00	.764756	2934.85	.235244	58
3	.940847	2082.32	.000000	.00	.940847	2082.32	.059153	57
4	7.065786	1615.17	.000000	.00	7.065786	1615.17	2.934214	56
5	7.162696	1319.68	10.000000	.02	7.162696	1319.70	2.837304	55
6	.241877	1115.78	9.999999	.00	.241878	1115.78	.758122	54
7	.308824	966.53	.999999	.00	.308825	966.53	.691175	53
8	.366816	852.53	.999999	.00	.366817	852.55	.633183	52
9	.417968	762.63	.999999	.02	.417970	762.62	.582030	51
10	7.463726	689.87	9.999998	.00	7.463727	689.88	2.536273	50
11	.505118	629.80	.999998	.02	.505120	629.82	.494880	49
12	.542906	579.37	.999997	.00	.542909	579.38	.457091	48
13	.577668	536.42	.999997	.02	.577672	536.42	.422328	47
14	.609853	499.38	.999996	.00	.609857	499.38	.390143	46
15	7.639816	467.15	9.999996	.02	7.639820	467.15	2.360180	45
16	.667845	438.80	.999995	.00	.667849	438.83	.332151	44
17	.694173	413.73	.999995	.02	.694179	413.73	.305821	43
18	.718997	391.35	.999994	.02	.719003	391.35	.280997	42
19	.742478	371.27	.999993	.00	.742484	371.28	.257516	41
20	7.764754	353.15	9.999993	.02	7.764761	353.17	2.235239	40
21	.785943	336.72	.999992	.02	.785951	336.73	.214049	39
22	.806146	321.75	.999991	.02	.806155	321.75	.193845	38
23	.825451	308.05	.999990	.02	.825460	308.07	.174540	37
24	.843934	295.47	.999989	.00	.843944	295.50	.156056	36
25	7.861662	283.88	9.999989	.02	7.861674	283.90	2.138326	35
26	.878695	273.17	.999988	.02	.878708	273.18	.121292	34
27	.895085	263.23	.999987	.02	.895099	263.25	.104901	33
28	.910879	254.00	.999986	.02	.910894	254.00	.089106	32
29	.926119	245.38	.999985	.03	.926134	245.40	.073866	31
30	7.940842	237.33	9.999983	.02	7.940858	237.37	2.059142	30
31	.955082	229.80	.999982	.02	.955100	229.82	.044900	29
32	.968870	222.72	.999981	.02	.968889	222.73	.031111	28
33	.982233	216.08	.999980	.02	.982253	216.10	.017747	27
34	.995198	209.82	.999979	.03	.995219	209.83	.004781	26
35	8.007787	203.90	9.999977	.02	8.007809	203.92	1.992191	25
36	.020021	198.30	.999976	.02	.020044	198.35	.979956	24
37	.031919	193.03	.999975	.03	.031945	193.03	.968055	23
38	.043501	188.00	.999973	.02	.043527	188.03	.956473	22
39	.054781	183.25	.999972	.02	.054809	183.28	.945191	21
40	8.065776	178.73	9.999971	.03	8.065806	178.75	1.934194	20
41	.076500	174.42	.999969	.02	.076531	174.43	.923469	19
42	.086965	170.30	.999968	.03	.086997	170.33	.913003	18
43	.097183	166.40	.999966	.03	.097217	166.43	.902783	17
44	.107167	162.65	.999964	.02	.107203	162.67	.892797	16
45	8.116926	159.08	9.999963	.03	8.116963	159.12	1.883037	15
46	.126471	155.65	.999961	.03	.126510	155.68	.873490	14
47	.135810	152.38	.999959	.02	.135851	152.42	.864149	13
48	.144953	149.23	.999958	.03	.144996	149.27	.855004	12
49	.153907	146.23	.999956	.03	.153952	146.25	.846048	11
50	8.162681	143.32	9.999954	.03	8.162727	143.35	1.837273	10
51	.171280	140.55	.999952	.03	.171328	140.58	.828672	9
52	.179713	137.87	.999950	.03	.179763	137.88	.820237	8
53	.187985	135.28	.999948	.03	.188036	135.33	.811964	7
54	.196102	132.80	.999946	.03	.196156	132.83	.803844	6
55	8.204070	130.42	9.999944	.03	8.204126	130.45	1.795874	5
56	.211895	128.10	.999942	.03	.211953	128.13	.788047	4
57	.219581	125.88	.999940	.03	219641	125.90	.780359	3
58	.227134	123.72	.999938	.03	.227195	123.77	.772805	2
59	.234557	121.63	.999936	.03	.234621	121.67	.765379	1
60	8.241855		9.999934		8.241921		1.758079	0
	Cos.	D. 1″.	Sin.	D. 1″.	Cot.	D. 1″.	Tan.	M.

90° | * From Allen's "Field and Office Tables." Copyright. | 89

1° 178

M.	Sin.	D. 1″.	Cos.	D. 1″.	Tan.	D. 1″.	Cot.	
0	8.241855	119.63	9.999934	.03	8.241921	119.68	1.758079	60
1	.249033	117.68	.999932	.05	.249102	117.72	.750898	59
2	.256094	115.80	.999929	.03	.256165	115.83	.743835	58
3	.263042	113.98	.999927	.03	.263115	114.02	.736885	57
4	.269881	112.22	.999925	.05	.269956	112.25	.730044	56
5	8.276614	110.48	9.999922	.03	8.276691	110.53	1.723309	55
6	.283243	108.83	.999920	.03	.283323	108.88	.716677	54
7	.289773	107.23	.999918	.05	.289856	107.27	.710144	53
8	.296207	105.65	.999915	.03	.296292	105.70	.703708	52
9	.302546	104.13	.999913	.05	.302634	104.17	.697366	51
10	8.308794	102.67	9.999910	.05	8.308884	102.70	1.691116	50
11	.314954	101.22	.999907	.03	.315046	101.27	.684954	49
12	.321027	99.82	.999905	.05	.321122	99.87	.678878	48
13	.327016	98.47	.999902	.05	.327114	98.52	.672886	47
14	.332924	97.15	.999899	.03	.333025	97.18	.666975	46
15	8.338753	95.85	9.999897	.05	8.338856	95.90	1.661144	45
16	.344504	94.62	.999894	.05	.344610	94.65	.655390	44
17	.350181	93.37	.999891	.05	.350289	93.43	.649711	43
18	.355783	92.20	.999888	.05	.355895	92.25	.644105	42
19	.361315	91.03	.999885	.05	.361430	91.08	.638570	41
20	8.366777	89.90	9.999882	.05	8.366895	89.95	1.633105	40
21	.372171	88.80	.999879	.05	.372292	88.83	.627708	39
22	.377499	87.72	.999876	.05	.377622	87.78	.622378	38
23	.382762	86.67	.999873	.05	.382889	86.72	.617111	37
24	.387962	85.65	.999870	.05	.388092	85.70	.611908	36
25	8.393101	84.63	9.999867	.05	8.393234	84.68	1.606766	35
26	.398179	83.67	.999864	.05	.398315	83.72	.601685	34
27	.403199	82.70	.999861	.05	.403338	82.77	.596662	33
28	.408161	81.78	.999858	.07	.408304	81.82	.591696	32
29	.413068	80.85	.999854	.05	.413213	80.92	.586787	31
30	8.417919	79.97	9.999851	.05	8.418068	80.02	1.581932	30
31	.422717	79.08	.999848	.07	.422869	79.15	.577131	29
32	.427462	78.23	.999844	.05	.427618	78.28	.572382	28
33	.432156	77.40	.999841	.05	.432315	77.45	.567685	27
34	.436800	76.57	.999838	.07	.436962	76.63	.563038	26
35	8.441394	75.78	9.999834	.05	8.441560	75.83	1.558440	25
36	.445941	74.98	.999831	.07	.446110	75.05	.553890	24
37	.450440	74.22	.999827	.05	.450613	74.28	.549387	23
38	.454893	73.47	.999824	.07	.455070	73.52	.544930	22
39	.459301	72.73	.999820	.07	.459481	72.80	.540519	21
40	8.463665	72.00	9.999816	.05	8.463849	72.05	1.536151	20
41	.467985	71.30	.999813	.07	.468172	71.37	.531828	19
42	.472263	70.58	.999809	.07	.472454	70.65	.527546	18
43	.476498	69.92	.999805	.07	.476693	69.98	.523307	17
44	.480693	69.25	.999801	.07	.480892	69.30	.519108	16
45	8.484848	68.58	9.999797	.05	8.485050	68.67	1.514950	15
46	.488963	67.95	.999794	.07	.489170	68.00	.510830	14
47	.493040	67.30	.999790	.07	.493250	67.38	.506750	13
48	.497078	66.70	.999786	.07	.497293	66.75	.502707	12
49	.501080	66.08	.999782	.07	.501298	66.15	.498702	11
50	8.505045	65.48	9.999778	.07	8.505267	65.55	1.494733	10
51	.508974	64.88	.999774	.08	.509200	64.97	.490800	9
52	.512867	64.32	.999769	.07	.513098	64.38	.486902	8
53	.516726	63.75	.999765	.07	.516961	63.82	.483039	7
54	.520551	63.20	.999761	.07	.520790	63.27	.479210	6
55	8.524343	62.65	9.999757	.07	8.524586	62.72	1.475414	5
56	.528102	62.10	.999753	.08	.528349	62.18	.471651	4
57	.531828	61.58	.999748	.07	.532080	61.65	.467920	3
58	.535523	61.05	.999744	.07	.535779	61.13	.464221	2
59	.539186	60.55	.999740	.08	.539447	60.62	.460553	1
60	8.542819		9.999735		8.543084		1.456916	0
	Cos.	D. 1″.	Sin.	D. 1″.	Cot.	D. 1″.	Tan.	M.

2° 177°

M.	Sin.	D. 1″.	Cos.	D. 1″.	Tan.	D. 1″.	Cot.	
0	8.542819	60.05	9.999735	.07	8.543084	60.12	1.456916	60
1	.546422	59.55	.999731	.08	.546691	59.62	.453309	59
2	.549995	59.07	.999726	.07	.550268	59.15	.449732	58
3	.553539	58.58	.999722	.08	.553817	58.65	.446183	57
4	.557054	58.10	.999717	.07	.557336	58.20	.442664	56
5	8.560540	57.65	9.999713	.08	8.560828	57.72	1.439172	55
6	.563999	57.20	.999708	.07	.564291	57.27	.435709	54
7	.567431	56.75	.999704	.08	.567727	56.83	.432273	53
8	.570836	56.30	.999699	.08	.571137	56.38	.428863	52
9	.574214	55.87	.999694	.08	.574520	55.95	.425480	51
10	8.577566	55.43	9.999689	.07	8.577877	55.52	1.422123	50
11	.580892	55.02	.999685	.08	.581208	55.10	.418792	49
12	.584193	54.60	.999680	.08	.584514	54.68	.415486	48
13	.587469	54.20	.999675	.08	.587795	54.27	.412205	47
14	.590721	53.78	.999670	.08	.591051	53.87	.408949	46
15	8.593948	53.40	9.999665	.08	8.594283	53.48	1.405717	45
16	.597152	53.00	.999660	.08	.597492	53.08	.402508	44
17	.600332	52.62	.999655	.08	.600677	52.70	.399323	43
18	.603489	52.23	.999650	.08	.603839	52.32	.396161	42
19	.606623	51.85	.999645	.08	.606978	51.93	.393022	41
20	8.609734	51.48	9.999640	.08	8.610094	51.58	1.389906	40
21	.612823	51.13	.999635	.10	.613189	51.22	.386811	39
22	.615891	50.77	.999629	.08	.616262	50.85	.383738	38
23	.618937	50.42	.999624	.08	.619313	50.50	.380687	37
24	.621962	50.05	.999619	.08	.622343	50.15	.377657	36
25	8.624965	49.72	9.999614	.10	8.625352	49.80	1.374648	35
26	.627948	49.38	.999608	.08	.628340	49.47	.371660	34
27	.630911	49.05	.999603	.10	.631308	49.13	.368692	33
28	.633854	48.70	.999597	.08	.634256	48.80	.365744	32
29	.636776	48.40	.999592	.10	.637184	48.48	.362816	31
30	8.639680	48.05	9.999586	.08	8.640093	48.15	1.359907	30
31	.642563	47.75	.999581	.10	.642982	47.85	.357018	29
32	.645428	47.43	.999575	.08	.645853	47.52	.354147	28
33	.648274	47.13	.999570	.10	.648704	47.22	.351296	27
34	.651102	46.82	.999564	.10	.651537	46.92	.348463	26
35	8.653911	46.52	9.999558	.08	8.654352	46.62	1.345648	25
36	.656702	46.22	.999553	.10	.657149	46.32	.342851	24
37	.659475	45.92	.999547	.10	.659928	46.02	.340072	23
38	.662230	45.63	.999541	.10	.662689	45.73	.337311	22
39	.664968	45.35	.999535	.10	.665433	45.45	.334567	21
40	8.667689	45.07	9.999529	.08	8.668160	45.17	1.331840	20
41	.670393	44.78	.999524	.10	.670870	44.88	.329130	19
42	.673080	44.52	.999518	.10	.673563	44.60	.326437	18
43	.675751	44.23	.999512	.10	.676239	44.35	.323761	17
44	.678405	43.97	.999506	.10	.678900	44.07	.321100	16
45	8.681043	43.70	9.999500	.12	8.681544	43.80	1.318456	15
46	.683665	43.45	.999493	.10	.684172	43.53	.315828	14
47	.686272	43.18	.999487	.10	.686784	43.28	.313216	13
48	.688863	42.92	.999481	.10	.689381	43.03	.310619	12
49	.691438	42.67	.999475	.10	.691963	42.77	.308037	11
50	8.693998	42.42	9.999469	.10	8.694529	42.53	1.305471	10
51	.696543	42.17	.999463	.12	.697081	42.27	.302919	9
52	.699073	41.93	.999456	.10	.699617	42.03	.300383	8
53	.701589	41.68	.999450	.12	.702139	41.78	.297861	7
54	.704090	41.45	.999443	.10	.704646	41.57	.295354	6
55	8.706577	41.20	9.999437	.10	8.707140	41.30	1.292860	5
56	.709049	40.97	.999431	.12	.709618	41.08	.290382	4
57	.711507	40.75	.999424	.10	.712083	40.85	.287917	3
58	.713952	40.52	.999418	.12	.714534	40.63	.285466	2
59	.716383	40.28	.999411	.12	.716972	40.40	.283028	1
60	8.718800		9.999404		8.719396		1.280604	0
	Cos.	D. 1″.	Sin.	D. 1″.	Cot.	D. 1″.	Tan.	M.

2° 87°

3° 176

M.	Sin.	D. 1″.	Cos.	D. 1″.	Tan.	D. 1″.	Cot.	
0	8.718800	40.07	9.999404	.10	8.719396	40.17	1.280604	60
1	.721204	39.85	.999398	.12	.721806	39.97	.278194	59
2	.723595	39.62	.999391	.12	.724204	39.73	.275796	58
3	.725972	39.42	.999384	.10	.726588	39.52	.273412	57
4	.728337	39.18	.999378	.12	.728959	39.30	.271041	56
5	8.730688	38.98	9.999371	.12	8.731317	39.10	1.268683	55
6	.733027	38.78	.999364	.12	.733663	38.88	.266337	54
7	.735354	38.55	.999357	.12	.735996	38.68	.264004	53
8	.737667	38.37	.999350	.12	.738317	38.48	.261683	52
9	.739969	38.17	.999343	.12	.740626	38.27	.259374	51
10	8.742259	37.95	9.999336	.12	8.742922	38.08	1.257078	50
11	.744536	37.77	.999329	.12	.745207	37.87	.254793	49
12	.746802	37.55	.999322	.12	.747479	37.68	.252521	48
13	.749055	37.37	.999315	.12	.749740	37.48	.250260	47
14	.751297	37.18	.999308	.12	.751989	37.30	.248011	46
15	8.753528	36.98	9.999301	.12	8.754227	37.10	1.245773	45
16	.755747	36.80	.999294	.12	.756453	36.92	.243547	44
17	.757955	36.60	.999287	.13	.758668	36.73	.241332	43
18	.760151	36.43	.999279	.12	.760872	36.55	.239128	42
19	.762337	36.23	.999272	.12	.763065	36.35	.236935	41
20	8.764511	36.07	9.999265	.13	8.765246	36.18	1.234754	40
21	.766675	35.88	.999257	.12	.767417	36.02	.232583	39
22	.768828	35.70	.999250	.13	.769578	35.82	.230422	38
23	.770970	35.52	.999242	.12	.771727	35.65	.228273	37
24	.773101	35.37	.999235	.13	.773866	35.48	.226134	36
25	8.775223	35.17	9.999227	.12	8.775995	35.32	1.224005	35
26	.777333	35.02	.999220	.13	.778114	35.13	.221886	34
27	.779434	34.83	.999212	.12	.780222	34.97	.219778	33
28	.781524	34.68	.999205	.13	.782320	34.80	.217680	32
29	.783605	34.50	.999197	.13	.784408	34.63	.215592	31
30	8.785675	34.35	9.999189	.13	8.786486	34.47	1.213514	30
31	.787736	34.18	.999181	.12	.788554	34.32	.211446	29
32	.789787	34.02	.999174	.13	.790613	34.15	.209387	28
33	.791828	33.85	.999166	.13	.792662	33.98	.207338	27
34	.793859	33.70	.999158	.13	.794701	33.83	.205299	26
35	8.795881	33.55	9.999150	.13	8.796731	33.68	1.203269	25
36	.797894	33.38	.999142	.13	.798752	33.52	.201248	24
37	.799897	33.25	.999134	.13	.800763	33.37	.199237	23
38	.801892	33.07	.999126	.13	.802765	33.22	.197235	22
39	.803876	32.93	.999118	.13	.804758	33.07	.195242	21
40	8.805852	32.78	9.999110	.13	8.806742	32.92	1.193258	20
41	.807819	32.63	.999102	.13	.808717	32.77	.191283	19
42	.809777	32.48	.999094	.13	.810683	32.63	.189317	18
43	.811726	32.35	.999086	.15	.812641	32.47	.187359	17
44	.813667	32.20	.999077	.13	.814589	32.33	.185411	16
45	8.815599	32.05	9.999069	.13	8.816529	32.20	1.183471	15
46	.817522	31.90	.999061	.13	.818461	32.05	.181539	14
47	.819436	31.78	.999053	.15	.820384	31.90	.179616	13
48	.821343	31.62	.999044	.13	.822298	31.78	.177702	12
49	.823240	31.50	.999036	.15	.824205	31.63	.175795	11
50	8.825130	31.35	9.999027	.13	8.826103	31.48	1.173897	10
51	.827011	31.22	.999019	.15	.827992	31.37	.172008	9
52	.828884	31.08	.999010	.13	.829874	31.23	.170126	8
53	.830749	30.97	.999002	.15	.831748	31.08	.168252	7
54	.832607	30.82	.998993	.15	.833613	30.97	.166387	6
55	8.834456	30.68	9.998984	.13	8.835471	30.83	1.164529	5
56	.836297	30.55	.998976	.15	.837321	30.70	.162679	4
57	.838130	30.43	.998967	.15	.839163	30.58	.160837	3
58	.839956	30.30	.998958	.13	.840998	30.45	.159002	2
59	.841774	30.18	.998950	.15	.842825	30.32	.157175	1
60	8.843585		9.998941		8.844644		1.155356	0
	Cos.	D. 1″.	Sin.	D. 1″.	Cot.	D. 1″.	Tan.	M

93° 86

4° 175°

M.	Sin.	D. 1″.	Cos.	D. 1″.	Tan.	D. 1″.	Cot.	
0	8.843585	30.03	9.998941	.15	8.844644	30.18	1.155356	60
1	.845387	29.93	.998932	.15	.846455	30.08	.153545	59
2	.847183	29.80	.998923	.15	.848260	29.95	.151740	58
3	.848971	29.67	.998914	.15	.850057	29.82	.149943	57
4	.850751	29.57	.998905	.15	.851846	29.70	.148154	56
5	8.852525	29.43	9.998896	.15	8.853628	29.58	1.146372	55
6	.854291	29.30	.998887	.15	.855403	29.47	.144597	54
7	.856049	29.20	.998878	.15	.857171	29.35	.142829	53
8	.857801	29.08	.998869	.15	.858932	29.23	.141068	52
9	.859546	28.95	.998860	.15	.860686	29.12	.139314	51
10	8.861283	28.85	9.998851	.17	8.862433	29.00	1.137567	50
11	.863014	28.73	.998841	.15	.864173	28.88	.135827	49
12	.864738	28.62	.998832	.15	.865906	28.77	.134094	48
13	.866455	28.50	.998823	.17	.867632	28.65	.132368	47
14	.868165	28.38	.998813	.15	.869351	28.55	.130649	46
15	8.869868	28.28	9.998804	.15	8.871064	28.43	1.128936	45
16	.871565	28.17	.998795	.17	.872770	28.32	.127230	44
17	.873255	28.05	.998785	.15	.874469	28.22	.125531	43
18	.874938	27.95	.998776	.17	.876162	28.12	.123838	42
19	.876615	27.83	.998766	.15	.877849	28.00	.122151	41
20	8.878285	27.73	9.998757	.17	8.879529	27.88	1.120471	40
21	.879949	27.63	.998747	.15	.881202	27.78	.118798	39
22	.881607	27.52	.998738	.17	.882869	27.68	.117131	38
23	.883258	27.42	.998728	.17	.884530	27.58	.115470	37
24	.884903	27.32	.998718	.17	.886185	27.47	.113815	36
25	8.886542	27.20	9.998708	.15	8.887833	27.38	1.112167	35
26	.888174	27.12	.998699	.17	.889476	27.27	.110524	34
27	.889801	27.00	.998689	.17	.891112	27.17	.108888	33
28	.891421	26.90	.998679	.17	.892742	27.07	.107258	32
29	.893035	26.80	.998669	.17	.894366	26.97	.105634	31
30	8.894643	26.72	9.998659	.17	8.895984	26.87	1.104016	30
31	.896246	26.60	.998649	.17	.897596	26.78	.102404	29
32	.897842	26.50	.998639	.17	.899203	26.67	.100797	28
33	.899432	26.42	.998629	.17	.900803	26.58	.099197	27
34	.901017	26.32	.998619	.17	.902398	26.48	.097602	26
35	8.902596	26.22	9.998609	.17	8.903987	26.38	1.096013	25
36	.904169	26.12	.998599	.17	.905570	26.28	.094430	24
37	.905736	26.02	.998589	.18	.907147	26.20	.092853	23
38	.907297	25.93	.998578	.17	.908719	26.10	.091281	22
39	.908853	25.85	.998568	.17	.910285	26.02	.089715	21
40	8.910404	25.75	9.998558	.17	8.911846	25.92	1.088154	20
41	.911949	25.65	.998548	.18	.913401	25.83	.086599	19
42	.913488	25.57	.998537	.17	.914951	25.73	.085049	18
43	.915022	25.47	.998527	.18	.916495	25.65	.083505	17
44	.916550	25.38	.998516	.17	.918034	25.57	.081966	16
45	8.918073	25.30	9.998506	.18	8.919568	25.47	1.080432	15
46	.919591	25.20	.998495	.17	.921096	25.38	.078904	14
47	.921103	25.12	.998485	.18	.922619	25.28	.077381	13
48	.922610	25.03	.998474	.17	.924136	25.22	.075864	12
49	.924112	24.95	.998464	.18	.925649	25.12	.074351	11
50	8.925609	24.85	9.998453	.18	8.927156	25.03	1.072844	10
51	.927100	24.78	.998442	.18	.928658	24.95	.071342	9
52	.928587	24.68	.998431	.17	.930155	24.87	.069845	8
53	.930068	24.60	.998421	.18	.931647	24.78	.068353	7
54	.931544	24.52	.998410	.18	.933134	24.70	.066866	6
55	8.933015	24.43	9.998399	.18	8.934616	24.62	1.065384	5
56	.934481	24.35	.998388	.18	.936093	24.53	.063907	4
57	.935942	24.27	.998377	.18	.937565	24.45	.062435	3
58	.937398	24.20	.998366	.18	.939032	24.37	.060968	2
59	.938850	24.10	.998355	.18	.940494	24.30	.059506	1
60	8.940296		9.998344		8.941952		1.058048	0
	Cos.	D. 1″.	Sin.	D. 1″.	Cot.	D. 1″.	Tan.	M.

94° 85°

5° **174°**

M.	Sin.	D. 1″.	Cos.	D. 1″.	Tan.	D. 1″.	Cot.	
0	8.940296	24.03	9.998344	.18	8.941952	24.20	1.058048	60
1	.941738	23.93	.998333	.18	.943404	24.13	.056596	59
2	.943174	23.87	.998322	.18	.944852	24.05	.055148	58
3	.944606	23.80	.998311	.18	.946295	23.98	.053705	57
4	.946034	23.70	.998300	.18	.947734	23.90	.052266	56
5	8.947456	23.63	9.998289	.20	8.949168	23.82	1.050832	55
6	.948874	23.55	.998277	.18	.950597	23.73	.049403	54
7	.950287	23.48	.998266	.18	.952021	23.67	.047979	53
8	.951696	23.40	.998255	.20	.953441	23.58	.046559	52
9	.953100	23.32	.998243	.18	.954856	23.52	.045144	51
10	8.954499	23.25	9.998232	.20	8.956267	23.45	1.043733	50
11	.955894	23.17	.998220	.18	.957674	23.35	.042326	49
12	.957284	23.10	.998209	.20	.959075	23.30	.040925	48
13	.958670	23.03	.998197	.18	.960473	23.22	.039527	47
14	.960052	22.95	.998186	.20	.961866	23.15	.038134	46
15	8.961429	22.87	9.998174	.18	8.963255	23.07	1.036745	45
16	.962801	22.82	.998163	.20	.964639	23.00	.035361	44
17	.964170	22.73	.998151	.20	.966019	22.92	.033981	43
18	.965534	22.65	.998139	.18	.967394	22.87	.032606	42
19	.966893	22.60	.998128	.20	.968766	22.78	.031234	41
20	8.968249	22.52	9.998116	.20	8.970133	22.72	1.029867	40
21	.969600	22.45	.998104	.20	.971496	22.65	.028504	39
22	.970947	22.37	.998092	.20	.972855	22.57	.027145	38
23	.972289	22.32	.998080	.20	.974209	22.52	.025791	37
24	.973628	22.23	.998068	.20	.975560	22.43	.024440	36
25	8.974962	22.18	9.998056	.20	8.976906	22.37	1.023094	35
26	.976293	22.10	.998044	.20	.978248	22.30	.021752	34
27	.977619	22.03	.998032	.20	.979586	22.25	.020414	33
28	.978941	21.97	.998020	.20	.980921	22.17	.019079	32
29	.980259	21.90	.998008	.20	.982251	22.10	.017749	31
30	8.981573	21.83	9.997996	.20	8.983577	22.03	1.016423	30
31	.982883	21.77	.997984	.20	.984899	21.97	.015101	29
32	.984189	21.70	.997972	.22	.986217	21.92	.013783	28
33	.985491	21.63	.997959	.20	.987532	21.83	.012468	27
34	.986789	21.57	.997947	.20	.988842	21.78	.011158	26
35	8.988083	21.52	9.997935	.22	8.990149	21.70	1.009851	25
36	.989374	21.43	.997922	.20	.991451	21.65	.008549	24
37	.990660	21.38	.997910	.22	.992750	21.58	.007250	23
38	.991943	21.32	.997897	.20	.994045	21.53	.005955	22
39	.993222	21.25	.997885	.22	.995337	21.45	.004663	21
40	8.994497	21.18	9.997872	.20	8.996624	21.40	1.003376	20
41	.995768	21.13	.997860	.22	.997908	21.33	.002092	19
42	.997036	21.05	.997847	.20	.999188	21.28	.000812	18
43	.998299	21.02	.997835	.22	9.000465	21.22	0.999535	17
44	.999560	20.93	.997822	.22	.001738	21.15	.998262	16
45	9.000816	20.88	9.997809	.20	9.003007	21.08	0.996993	15
46	.002069	20.82	.997797	.22	.004272	21.03	.995728	14
47	.003318	20.75	.997784	.22	.005534	20.97	.994466	13
48	.004563	20.70	.997771	.22	.006792	20.92	.993208	12
49	.005805	20.65	.997758	.22	.008047	20.85	.991953	11
50	9.007044	20.57	9.997745	.22	9.009298	20.80	0.990702	10
51	.008278	20.53	.997732	.22	.010546	20.73	.989454	9
52	.009510	20.45	.997719	.22	.011790	20.68	.988210	8
53	.010737	20.42	.997706	.22	.013031	20.62	986969	7
54	.011962	20.33	.997693	.22	.014268	20.57	.985732	6
55	9.013182	20.30	9.997680	.22	9.015502	20.50	0.984498	5
56	.014400	20.22	.997667	.22	.016732	20.45	983268	4
57	.015613	20.18	.997654	.22	.017959	20.40	982041	3
58	.016824	20.12	.997641	.22	.019183	20.33	.980817	2
59	.018031	20.07	.997628	.23	.020403	20.28	.979597	1
60	9.019235		9.997614		9.021620		0.978380	0
	Cos.	D. 1″.	Sin.	D. 1″.	Cot.	D. 1″.	Tan.	M.

95° **84°**

6° 173°

M.	Sin.	D. 1″.	Cos.	D. 1″.	Tan.	D. 1″.	Cot.	
0	9.019235	20.00	9.997614	.22	9.021620	20.23	0.978380	60
1	.020435	19.95	.997601	.22	.022834	20.17	.977166	59
2	.021632	19.88	.997588	.23	.024044	20.12	.975956	58
3	.022825	19.85	.997574	.22	.025251	20.07	.974749	57
4	.024016	19.78	.997561	.23	.026455	20.00	.973545	56
5	9.025203	19.72	9.997547	.22	9.027655	19.95	0.972345	55
6	.026386	19.68	.997534	.23	.028852	19.90	.971148	54
7	.027567	19.62	.997520	.22	.030046	19.85	.969954	53
8	.028744	19.57	.997507	.23	.031237	19.80	.968763	52
9	.029918	19.52	.997493	.22	.032425	19.73	.967575	51
10	9.031089	19.47	9.997480	.23	9.033609	19.70	0.966391	50
11	.032257	19.40	.997466	.23	.034791	19.63	.965209	49
12	.033421	19.35	.997452	.22	.035969	19.58	.964031	48
13	.034582	19.32	.997439	.23	.037144	19.53	.962856	47
14	.035741	19.25	.997425	.23	.038316	19.48	.961684	46
15	9.036896	19.20	9.997411	.23	9.039485	19.43	0.960515	45
16	.038048	19.15	.997397	.23	.040651	19.37	.959349	44
17	.039197	19.08	.997383	.23	.041813	19.33	.958187	43
18	.040342	19.05	.997369	.23	.042973	19.28	.957027	42
19	.041485	19.00	.997355	.23	.044130	19.23	.955870	41
20	9.042625	18.95	9.997341	.23	9.045284	19.17	0.954716	40
21	.043762	18.88	.997327	.23	.046434	19.13	.953566	39
22	.044895	18.85	.997313	.23	.047582	19.08	.952418	38
23	.046026	18.80	.997299	.23	.048727	19.03	.951273	37
24	.047154	18.75	.997285	.23	.049869	18.98	.950131	36
25	9.048279	18.68	9.997271	.23	9.051008	18.93	0.948992	35
26	.049400	18.65	.997257	.25	.052144	18.88	.947856	34
27	.050519	18.60	.997242	.23	.053277	18.83	.946723	33
28	.051635	18.57	.997228	.23	.054407	18.80	.945593	32
29	.052749	18.50	.997214	.25	.055535	18.73	.944465	31
30	9.053859	18.45	9.997199	.23	9.056659	18.70	0.943341	30
31	.054966	18.42	.997185	.25	.057781	18.65	.942219	29
32	.056071	18.35	.997170	.23	.058900	18.60	.941100	28
33	.057172	18.32	.997156	.25	.060016	18.57	.939984	27
34	.058271	18.27	.997141	.23	.061130	18.50	.938870	26
35	9.059367	18.22	9.997127	.25	9.062240	18.47	0.937760	25
36	.060460	18.18	.997112	.23	.063348	18.42	.936652	24
37	.061551	18.13	.997098	.25	.064453	18.38	.935547	23
38	.062639	18.08	.997083	.25	.065556	18.32	.934444	22
39	.063724	18.03	.997068	.25	.066655	18.28	.933345	21
40	9.064806	17.98	9.997053	.23	9.067752	18.23	0.932248	20
41	.065885	17.95	.997039	.25	.068846	18.20	.931154	19
42	.066962	17.90	.997024	.25	.069938	18.15	.930062	18
43	.068036	17.85	.997009	.25	.071027	18.10	.928973	17
44	.069107	17.82	.996994	.25	.072113	18.07	.927887	16
45	9.070176	17.77	9.996979	.25	9.073197	18.02	0.926803	15
46	.071242	17.73	.996964	.25	.074278	17.97	.925722	14
47	.072306	17.67	.996949	.25	.075356	17.93	.924644	13
48	.073366	17.63	.996934	.25	.076432	17.88	.923568	12
49	.074424	17.60	.996919	.25	.077505	17.85	.922495	11
50	9.075480	17.55	9.996904	.25	9.078576	17.80	0.921424	10
51	.076533	17.50	.996889	.25	.079644	17.77	.920356	9
52	.077583	17.47	.996874	.27	.080710	17.72	.919290	8
53	.078631	17.42	.996858	.25	.081773	17.67	.918227	7
54	.079676	17.38	.996843	.25	.082833	17.63	.917167	6
55	9.080719	17.33	9.996828	.27	9.083891	17.60	0.916109	5
56	.081759	17.30	.996812	.25	.084947	17.55	.915053	4
57	.082797	17.25	.996797	.25	.086000	17.50	.914000	3
58	.083832	17.20	.996782	.27	.087050	17.47	.912950	2
59	.084864	17.17	.996766	.25	.088098	17.43	.911902	1
60	9.085894		9.996751		9.089144		0.910856	0
	Cos.	D. 1″.	Sin.	D. 1″.	Cot.	D. 1″.	Tan.	M.

96° 83°

7° 172°

M.	Sin.	D. 1″.	Cos.	D. 1″.	Tan.	D. 1″.	Cot.	
0	9.085894	17.13	9.996751	.27	9.089144	17.38	0.910856	60
1	.086922	17.08	.996735	.25	.090187	17.35	.909813	59
2	.087947	17.05	.996720	.27	.091228	17.30	.908772	58
3	.088970	17.00	.996704	.27	.092266	17.27	.907734	57
4	.089990	16.97	.996688	.25	.093302	17.23	.906698	56
5	9.091008	16.93	9.996673	.27	9.094336	17.18	0.905664	55
6	.092024	16.88	.996657	.27	.095367	17.13	.904633	54
7	.093037	16.83	.996641	.27	.096395	17.12	.903605	53
8	.094047	16.82	.996625	.25	.097422	17.07	.902578	52
9	.095056	16.77	.996610	.27	.098446	17.03	.901554	51
10	9.096062	16.72	9.996594	.27	9.099468	16.98	0.900532	50
11	.097065	16.68	.996578	.27	.100487	16.95	.899513	49
12	.098066	16.65	.996562	.27	.101504	16.92	.898496	48
13	.099065	16.62	.996546	.27	.102519	16.88	.897481	47
14	.100062	16.57	.996530	.27	.103532	16.83	.896468	46
15	9.101056	16.53	9.996514	.27	9.104542	16.80	0.895458	45
16	.102048	16.48	.996498	.27	.105550	16.77	.894450	44
17	.103037	16.47	.996482	.28	.106556	16.72	.893444	43
18	.104025	16.42	.996465	.27	.107559	16.68	.892441	42
19	.105010	16.37	.996449	.27	.108560	16.65	.891440	41
20	9.105992	16.35	9.996433	.27	9.109559	16.62	0.890441	40
21	.106973	16.30	.996417	.28	.110556	16.58	.889444	39
22	.107951	16.27	.996400	.27	.111551	16.53	.888449	38
23	.108927	16.23	.996384	.27	.112543	16.50	.887457	37
24	.109901	16.20	.996368	.28	.113533	16.47	.886467	36
25	9.110873	16.15	9.996351	.27	9.114521	16.43	0.885479	35
26	.111842	16.12	.996335	.28	.115507	16.40	.884493	34
27	.112809	16.08	.996318	.27	.116491	16.35	.883509	33
28	.113774	16.05	.996302	.28	.117472	16.33	.882528	32
29	.114737	16.02	.996285	.27	.118452	16.28	.881548	31
30	9.115698	15.97	9.996269	.28	9.119429	16.25	0.880571	30
31	.116656	15.95	.996252	.28	.120404	16.22	.879596	29
32	.117613	15.90	.996235	.27	.121377	16.18	.878623	28
33	.118567	15.87	.996219	.28	.122348	16.15	.877652	27
34	.119519	15.83	.996202	.28	.123317	16.12	.876683	26
35	9.120469	15.80	9.996185	.28	9.124284	16.08	0.875716	25
36	.121417	15.75	.996168	.28	.125249	16.03	.874751	24
37	.122362	15.73	.996151	.28	.126211	16.02	.873789	23
38	.123306	15.70	.996134	.28	.127172	15.97	.872828	22
39	.124248	15.65	.996117	.28	.128130	15.95	.871870	21
40	9.125187	15.63	9.996100	.28	9.129087	15.90	0.870913	20
41	.126125	15.58	.996083	.28	.130041	15.88	.869959	19
42	.127060	15.55	.996066	.28	.130994	15.83	.869006	18
43	.127993	15.53	.996049	.28	.131944	15.82	.868056	17
44	.128925	15.48	.996032	.28	.132893	15.77	.867107	16
45	9.129854	15.45	9.996015	.28	9.133839	15.75	0.866161	15
46	.130781	15.42	.995998	.30	.134784	15.70	.865216	14
47	.131706	15.40	.995980	.28	.135726	15.68	.864274	13
48	.132630	15.35	.995963	.28	.136667	15.63	.863333	12
49	.133551	15.32	.995946	.30	.137605	15.62	.862395	11
50	9.134470	15.28	9.995928	.28	9.138542	15.57	0.861458	10
51	.135387	15.27	.995911	.28	.139476	15.55	.860524	9
52	.136303	15.22	.995894	.30	.140409	15.52	.859591	8
53	.137216	15.20	.995876	.28	.141340	15.48	.858660	7
54	.138128	15.15	.995859	.30	.142269	15.45	.857731	6
55	9.139037	15.12	9.995841	.30	9.143196	15.42	0.856804	5
56	.139944	15.10	.995823	.28	.144121	15.38	.855879	4
57	.140850	15.07	.995806	.30	.145044	15.37	.854956	3
58	.141754	15.02	.995788	.28	.145966	15.32	.854034	2
59	.142655	15.00	.995771	.30	.146885	15.30	.853115	1
60	9.143555		9.995753		9.147803		0.852197	0
	Cos.	D. 1″.	Sin.	D. 1″.	Cot.	D. 1″.	Tan.	M.

97° 82°

8° 171°

M.	Sin.	D. 1″.	Cos.	D. 1″.	Tan.	D. 1″.	Cot.	
0	9.143555	14.97	9.995753	.30	9.147803	15.25	0.852197	60
1	.144453	14.93	.995735	.30	.148718	15.23	.851282	59
2	.145349	14.90	.995717	.30	.149632	15.20	.850368	58
3	.146243	14.88	.995699	.30	.150544	15.17	.849456	57
4	.147136	14.83	.995681	.28	.151454	15.15	.848546	56
5	9.148026	14.82	9.995664	.30	9.152363	15.10	0.847637	55
6	.148915	14.78	.995646	.30	.153269	15.08	.846731	54
7	.149802	14.73	.995628	.30	.154174	15.05	.845826	53
8	.150686	14.72	.995610	.32	.155077	15.02	.844923	52
9	.151569	14.70	.995591	.30	.155978	14.98	.844022	51
10	9.152451	14.65	9.995573	.30	9.156877	14.97	0.843123	50
11	.153330	14.63	.995555	.30	.157775	14.93	.842225	49
12	.154208	14.58	.995537	.30	.158671	14.90	.841329	48
13	.155083	14.57	.995519	.30	.159565	14.87	.840435	47
14	.155957	14.55	.995501	.32	.160457	14.83	.839543	46
15	9.156830	14.50	9.995482	.30	9.161347	14.82	0.838653	45
16	.157700	14.48	.995464	.30	.162236	14.78	.837764	44
17	.158569	14.43	.995446	.32	.163123	14.75	.836877	43
18	.159435	14.43	.995427	.30	.164008	14.73	.835992	42
19	.160301	14.38	.995409	.32	.164892	14.70	.835108	41
20	9.161164	14.35	9.995390	.30	9.165774	14.67	0.834226	40
21	.162025	14.33	.995372	.32	.166654	14.63	.833346	39
22	.162885	14.30	.995353	.32	.167532	14.62	.832468	38
23	.163743	14.28	.995334	.30	.168409	14.58	.831591	37
24	.164600	14.23	.995316	.32	.169284	14.55	.830716	36
25	9.165454	14.22	9.995297	.32	9.170157	14.53	0.829843	35
26	.166307	14.20	.995278	.30	.171029	14.50	.828971	34
27	.167159	14.15	.995260	.32	.171899	14.47	.828101	33
28	.168008	14.13	.995241	.32	.172767	14.45	.827233	32
29	.168856	14.10	.995222	.32	.173634	14.42	.826366	31
30	9.169702	14.08	9.995203	.32	9.174499	14.38	0.825501	30
31	.170547	14.03	.995184	.32	.175362	14.37	.824638	29
32	.171389	14.02	.995165	.32	.176224	14.33	.823776	28
33	.172230	14.00	.995146	.32	.177084	14.30	.822916	27
34	.173070	13.97	.995127	.32	.177942	14.28	.822058	26
35	9.173908	13.93	9.995108	.32	9.178799	14.27	0.821201	25
36	.174744	13.90	.995089	.32	.179655	14.22	.820345	24
37	.175578	13.88	.995070	.32	.180508	14.20	.819492	23
38	.176411	13.85	.995051	.32	.181360	14.18	.818640	22
39	.177242	13.83	.995032	.32	.182211	14.13	.817789	21
40	9.178072	13.80	9.995013	.33	9.183059	14.13	0.816941	20
41	.178900	13.77	.994993	.32	.183907	14.08	.816093	19
42	.179726	13.75	.994974	.32	.184752	14.08	.815248	18
43	.180551	13.72	.994955	.33	.185597	14.03	.814403	17
44	.181374	13.70	.994935	.32	.186439	14.02	.813561	16
45	9.182196	13.67	9.994916	.33	9.187280	14.00	0.812720	15
46	.183016	13.63	.994896	.32	.188120	13.97	.811880	14
47	.183834	13.62	.994877	.33	.188958	13.93	.811042	13
48	.184651	13.58	.994857	.32	.189794	13.92	.810206	12
49	.185466	13.57	.994838	.33	.190629	13.88	.809371	11
50	9.186280	13.53	9.994818	.33	9.191462	13.87	0.808538	10
51	.187092	13.52	.994798	.32	.192294	13.83	.807706	9
52	.187903	13.48	.994779	.33	.193124	13.82	.806876	8
53	.188712	13.45	.994759	.33	.193953	13.78	.806047	7
54	.189519	13.43	.994739	.32	.194780	13.77	.805220	6
55	9.190325	13.42	9.994720	.33	9.195606	13.73	0.804394	5
56	.191130	13.38	.994700	.33	.196430	13.72	.803570	4
57	.191933	13.35	.994680	.33	.197253	13.68	.802747	3
58	.192734	13.33	.994660	.33	.198074	13.67	.801926	2
59	.193534	13.30	.994640	.33	.198894	13.65	.801106	1
60	9.194332		9.994620		9.199713		0.800287	0
	Cos.	D. 1″.	Sin.	D. 1″.	Cot.	D. 1″.	Tan.	M.

98° 81°

9° | 170°

M.	Sin.	D. 1″.	Cos.	D. 1″.	Tan.	D. 1″.	Cot.	
0	9.194332	13.28	9.994620	.33	9.199713	13.60	0.800287	60
1	.195129	13.27	.994600	.33	.200529	13.60	.799471	59
2	.195925	13.23	.994580	.33	.201345	13.57	.798655	58
3	.196719	13.20	.994560	.33	.202159	13.53	.797841	57
4	.197511	13.18	.994540	.35	.202971	13.52	.797029	56
5	9.198302	13.15	9.994519	.33	9.203782	13.50	0.796218	55
6	.199091	13.13	.994499	.33	.204592	13.47	.795408	54
7	.199879	13.12	.994479	.33	.205400	13.45	.794600	53
8	.200666	13.08	.994459	.35	.206207	13.43	.793793	52
9	.201451	13.05	.994438	.33	.207013	13.40	.792987	51
10	9.202234	13.05	9.994418	.33	9.207817	13.37	0.792183	50
11	.203017	13.00	.994398	.35	.208619	13.35	.791381	49
12	.203797	13.00	.994377	.33	.209420	13.33	.790580	48
13	.204577	12.95	.994357	.35	.210220	13.30	.789780	47
14	.205354	12.95	.994336	.33	.211018	13.28	.788982	46
15	9.206131	12.92	9.994316	.35	9.211815	13.27	0.788185	45
16	.206906	12.88	.994295	.35	.212611	13.23	.787389	44
17	.207679	12.88	.994274	.33	.213405	13.22	.786595	43
18	.208452	12.83	.994254	.35	.214198	13.18	.785802	42
19	.209222	12.83	.994233	.35	.214989	13.18	.785011	41
20	9.209992	12.80	9.994212	.35	9.215780	13.13	0.784220	40
21	.210760	12.77	.994191	.33	.216568	13.13	.783432	39
22	.211526	12.75	.994171	.35	.217356	13.10	.782644	38
23	.212291	12.73	.994150	.35	.218142	13.07	.781858	37
24	.213055	12.72	.994129	.35	.218926	13.07	.781074	36
25	9.213818	12.68	9.994108	.35	9.219710	13.03	0.780290	35
26	.214579	12.65	.994087	.35	.220492	13.00	.779508	34
27	.215338	12.65	.994066	.35	.221272	13.00	.778728	33
28	.216097	12.62	.994045	.35	.222052	12.97	.777948	32
29	.216854	12.58	.994024	.35	.222830	12.95	.777170	31
30	9.217609	12.57	9.994003	.35	9.223607	12.92	0.776393	30
31	.218363	12.55	.993982	.37	.224382	12.90	.775618	29
32	.219116	12.53	.993960	.35	.225156	12.88	.774844	28
33	.219868	12.50	.993939	.35	.225929	12.85	.774071	27
34	.220618	12.48	.993918	.35	.226700	12.85	.773300	26
35	9.221367	12.47	9.993897	.37	9.227471	12.80	0.772529	25
36	.222115	12.43	.993875	.35	.228239	12.80	.771761	24
37	.222861	12.42	.993854	.37	.229007	12.77	.770993	23
38	.223606	12.38	.993832	.35	.229773	12.77	.770227	22
39	.224349	12.38	.993811	.37	.230539	12.72	.769461	21
40	9.225092	12.35	9.993789	.35	9.231302	12.72	0.768698	20
41	.225833	12.33	.993768	.37	.232065	12.68	.767935	19
42	.226573	12.30	.993746	.35	.232826	12.67	.767174	18
43	.227311	12.28	.993725	.37	.233586	12.65	.766414	17
44	.228048	12.27	.993703	.37	.234345	12.63	.765655	16
45	9.228784	12.23	9.993681	.35	9.235103	12.60	0.764897	15
46	.229518	12.23	.993660	.37	.235859	12.58	.764141	14
47	.230252	12.20	.993638	.37	.236614	12.57	.763386	13
48	.230984	12.18	.993616	.37	.237368	12.53	.762632	12
49	.231715	12.15	.993594	.37	.238120	12.53	.761880	11
50	9.232444	12.13	9.993572	.37	9.238872	12.50	0.761128	10
51	.233172	12.12	.993550	.37	.239622	12.48	.760378	9
52	.233899	12.10	.993528	.37	.240371	12.45	.759629	8
53	.234625	12.07	.993506	.37	.241118	12.45	.758882	7
54	.235349	12.07	.993484	.37	.241865	12.42	.758135	6
55	9.236073	12.03	9.993462	.37	9.242610	12.40	0.757390	5
56	.236795	12.00	.993440	.37	.243354	12.38	.756646	4
57	.237515	12.00	.993418	.37	.244097	12.37	.755903	3
58	.238235	11.97	.993396	.37	.244839	12.33	.755161	2
59	.238953	11.95	.993374	.38	.245579	12.33	.754421	1
60	9.239670		9.993351		9.246319		0.753681	0
	Cos.	D. 1″.	Sin.	D. 1″.	Cot.	D. 1″.	Tan.	M.

99° | 80°

10° 169°

M.	Sin.	D. 1″.	Cos.	D. 1″.	Tan.	D. 1″.	Cot.	
0	9.239670	11.93	9.993351	.37	9.246319	12.30	0.753681	60
1	.240386	11.92	.993329	.37	.247057	12.28	.752943	59
2	.241101	11.88	.993307	.38	.247794	12.27	.752206	58
3	.241814	11.87	.993284	.37	.248530	12.23	.751470	57
4	.242526	11.85	.993262	.37	.249264	12.23	.750736	56
5	9.243237	11.83	9.993240	.38	9.249998	12.20	0.750002	55
6	.243947	11.82	.993217	.37	.250730	12.18	.749270	54
7	.244656	11.78	.993195	.38	.251461	12.17	.748539	53
8	.245363	11.77	.993172	.38	.252191	12.15	.747809	52
9	.246069	11.77	.993149	.37	.252920	12.13	.747080	51
10	9.246775	11.72	9.993127	.38	9.253648	12.10	0.746352	50
11	.247478	11.72	.993104	.38	.254374	12.10	.745626	49
12	.248181	11.70	.993081	.37	.255100	12.07	.744900	48
13	.248883	11.67	.993059	.38	.255824	12.05	.744176	47
14	.249583	11.65	.993036	.38	.256547	12.03	.743453	46
15	9.250282	11.63	9.993013	.38	9.257269	12.02	0.742731	45
16	.250980	11.62	.992990	.38	.257990	12.00	.742010	44
17	.251677	11.60	.992967	.38	.258710	11.98	.741290	43
18	.252373	11.57	.992944	.38	.259429	11.95	.740571	42
19	.253067	11.57	.992921	.38	.260146	11.95	.739854	41
20	9.253761	11.53	9.992898	.38	9.260863	11.92	0.739137	40
21	.254453	11.52	.992875	.38	.261578	11.90	.738422	39
22	.255144	11.50	.992852	.38	.262292	11.88	.737708	38
23	.255834	11.48	.992829	.38	.263005	11.87	.736995	37
24	.256523	11.47	.992806	.38	.263717	11.85	.736283	36
25	9.257211	11.45	9.992783	.40	9.264428	11.83	0.735572	35
26	.257898	11.42	.992759	.38	.265138	11.82	.734862	34
27	.258583	11.42	.992736	.38	.265847	11.80	.734153	33
28	.259268	11.38	.992713	.38	.266555	11.77	.733445	32
29	.259951	11.37	.992690	.40	.267261	11.77	.732739	31
30	9.260633	11.35	9.992666	.38	9.267967	11.73	0.732033	30
31	.261314	11.33	.992643	.40	.268671	11.73	.731329	29
32	.261994	11.32	.992619	.38	.269375	11.70	.730625	28
33	.262673	11.30	.992596	.40	.270077	11.70	.729923	27
34	.263351	11.27	.992572	.38	.270779	11.67	.729221	26
35	9.264027	11.27	9.992549	.40	9.271479	11.65	0.728521	25
36	.264703	11.23	.992525	.40	.272178	11.63	.727822	24
37	.265377	11.23	.992501	.38	.272876	11.62	.727124	23
38	.266051	11.20	.992478	.40	.273573	11.60	.726427	22
39	.266723	11.20	.992454	.40	.274269	11.58	.725731	21
40	9.267395	11.17	9.992430	.40	9.274964	11.57	0.725036	20
41	.268065	11.15	.992406	.40	.275658	11.55	.724342	19
42	.268734	11.13	.992382	.38	.276351	11.53	.723649	18
43	.269402	11.12	.992359	.40	.277043	11.52	.722957	17
44	.270069	11.10	.992335	.40	.277734	11.50	.722266	16
45	9.270735	11.08	9.992311	.40	9.278424	11.48	0.721576	15
46	.271400	11.07	.992287	.40	.279113	11.47	.720887	14
47	.272064	11.03	.992263	.40	.279801	11.45	.720199	13
48	.272726	11.03	.992239	.42	.280488	11.43	.719512	12
49	.273388	11.02	.992214	.40	.281174	11.40	.718826	11
50	9.274049	10.98	9.992190	.40	9.281858	11.40	0.718142	10
51	.274708	10.98	.992166	.40	.282542	11.38	.717458	9
52	.275367	10.97	.992142	.40	.283225	11.37	.716775	8
53	.276025	10.93	.992118	.42	.283907	11.35	.716093	7
54	.276681	10.93	.992093	.40	.284588	11.33	.715412	6
55	9.277337	10.90	9.992069	.42	9.285268	11.32	0.714732	5
56	.277991	10.90	.992044	.40	.285947	11.28	.714053	4
57	.278645	10.87	.992020	.40	.286624	11.28	.713376	3
58	.279297	10.85	.991996	.42	.287301	11.27	.712699	2
59	.279948	10.85	.991971	.40	.287977	11.25	.712023	1
60	9.280599		9.991947		9.288652		0.711348	0
	Cos.	D. 1″.	Sin.	D. 1″.	Cot.	D. 1″.	Tan.	M.

100° 79°

11° 168°

M.	Sin.	D. 1″.	Cos.	D. 1″.	Tan.	D. 1″.	Cot.	
0	9.280599	10.82	9.991947	.42	9.288652	11.23	0.711348	60
1	.281248	10.82	.991922	.42	.289326	11.22	.710674	59
2	.281897	10.78	.991897	.40	.289999	11.20	.710001	58
3	.282544	10.77	.991873	.42	.290671	11.18	.709329	57
4	.283190	10.77	.991848	.42	.291342	11.18	.708658	56
5	9.283836	10.73	9.991823	.40	9.292013	11.15	0.707987	55
6	.284480	10.73	.991799	.42	.292682	11.13	.707318	54
7	.285124	10.70	.991774	.42	.293350	11.12	.706650	53
8	.285766	10.70	.991749	.42	.294017	11.12	.705983	52
9	.286408	10.67	.991724	.42	.294684	11.08	.705316	51
10	9.287048	10.67	9.991699	.42	9.295349	11.07	0.704651	50
11	.287688	10.63	.991674	.42	.296013	11.07	.703987	49
12	.288326	10.63	.991649	.42	.296677	11.03	.703323	48
13	.288964	10.60	.991624	.42	.297339	11.03	.702661	47
14	.289600	10.60	.991599	.42	.298001	11.02	.701999	46
15	9.290236	10.57	9.991574	.42	9.298662	11.00	0.701338	45
16	.290870	10.57	.991549	.42	.299322	10.97	.700678	44
17	.291504	10.55	.991524	.43	.299980	10.97	.700020	43
18	.292137	10.52	.991498	.42	.300638	10.95	.699362	42
19	.292768	10.52	.991473	.42	.301295	10.93	.698705	41
20	9.293399	10.50	9.991448	.43	9.301951	10.93	0.698049	40
21	.294029	10.48	.991422	.42	.302607	10.90	.697393	39
22	.294658	10.47	.991397	.42	.303261	10.88	.696739	38
23	.295286	10.45	.991372	.43	.303914	10.88	.696086	37
24	.295913	10.43	.991346	.42	.304567	10.85	.695433	36
25	9.296539	10.42	9.991321	.43	9.305218	10.85	0.694782	35
26	.297164	10.40	.991295	.42	.305869	10.83	.694131	34
27	.297788	10.40	.991270	.43	.306519	10.82	.693481	33
28	.298412	10.37	.991244	.43	.307168	10.80	.692832	32
29	.299034	10.35	.991218	.42	.307816	10.78	.692184	31
30	9.299655	10.35	9.991193	.43	9.308463	10.77	0.691537	30
31	.300276	10.32	.991167	.43	.309109	10.75	.690891	29
32	.300895	10.32	.991141	.43	.309754	10.75	.690246	28
33	.301514	10.30	.991115	.42	.310399	10.72	.689601	27
34	.302132	10.27	.991090	.43	.311042	10.72	.688958	26
35	9.302748	10.27	9.991064	.43	9.311685	10.70	0.688315	25
36	.303364	10.25	.991038	.43	.312327	10.68	.687673	24
37	.303979	10.23	.991012	.43	.312968	10.67	.687032	23
38	.304593	10.23	.990986	.43	.313608	10.65	.686392	22
39	.305207	10.20	.990960	.43	.314247	10.63	.685753	21
40	9.305819	10.18	9.990934	.43	9.314885	10.63	0.685115	20
41	.306430	10.18	.990908	.43	.315523	10.60	.684477	19
42	.307041	10.15	.990882	.45	.316159	10.60	.683841	18
43	.307650	10.15	.990855	.43	.316795	10.58	.683205	17
44	.308259	10.13	.990829	.43	.317430	10.57	.682570	16
45	9.308867	10.12	9.990803	.43	9.318064	10.55	0.681936	15
46	.309474	10.10	.990777	.45	.318697	10.55	.681303	14
47	.310080	10.08	.990750	.43	.319330	10.52	.680670	13
48	.310685	10.07	.990724	.45	.319961	10.52	.680039	12
49	.311289	10.07	.990697	.43	.320592	10.50	.679408	11
50	9.311893	10.03	9.990671	.43	9.321222	10.48	0.678778	10
51	.312495	10.03	.990645	.45	.321851	10.47	.678149	9
52	.313097	10.02	.990618	.45	.322479	10.45	.677521	8
53	.313698	9.98	.990591	.43	.323106	10.45	.676894	7
54	.314297	10.00	.990565	.45	.323733	10.42	.676267	6
55	9.314897	9.97	9.990538	.45	9.324358	10.42	0.675642	5
56	.315495	9.95	.990511	.43	.324983	10.40	.675017	4
57	.316092	9.95	.990485	.45	.325607	10.40	.674393	3
58	.316689	9.92	.990458	.45	.326231	10.37	.673769	2
59	.317284	9.92	.990431	.45	.326853	10.37	.673147	1
60	9.317879		9.990404		9.327475		0.672525	0
	Cos.	D. 1″.	Sin.	D. 1″.	Cot.	D. 1″.	Tan.	M

101° 78°

12° 167°

M.	Sin.	D. 1″.	Cos.	D. 1″.	Tan.	D. 1″.	Cot.	
0	9.317879	9.90	9.990404	.43	9.327475	10.33	0.672525	60
1	.318473	9.88	.990378	.45	.328095	10.33	.671905	59
2	.319066	9.87	.990351	.45	.328715	10.32	.671285	58
3	.319658	9.85	.990324	.45	.329334	10.32	.670666	57
4	.320249	9.85	.990297	.45	.329953	10.28	.670047	56
5	9.320840	9.83	9.990270	.45	9.330570	10.28	0.669430	55
6	.321430	9.82	.990243	.47	.331187	10.27	.668813	54
7	.322019	9.80	.990215	.45	.331803	10.25	.668197	53
8	.322607	9.78	.990188	.45	.332418	10.25	.667582	52
9	.323194	9.77	.990161	.45	.333033	10.22	.666967	51
10	9.323780	9.77	9.990134	.45	9.333646	10.22	0.666354	50
11	.324366	9.73	.990107	.47	.334259	10.20	.665741	49
12	.324950	9.73	.990079	.45	.334871	10.18	.665129	48
13	.325534	9.72	.990052	.45	.335482	10.18	.664518	47
14	.326117	9.72	.990025	.47	.336093	10.15	.663907	46
15	9.326700	9.68	9.989997	.45	9.336702	10.15	0.663298	45
16	.327281	9.68	.989970	.47	.337311	10.13	.662689	44
17	.327862	9.67	.989942	.45	.337919	10.13	.662081	43
18	.328442	9.65	.989915	.47	.338527	10.10	.661473	42
19	.329021	9.63	.989887	.45	.339133	10.10	.660867	41
20	9.329599	9.62	9.989860	.47	9.339739	10.08	0.660261	40
21	.330176	9.62	.989832	.47	.340344	10.07	.659656	39
22	.330753	9.60	.989804	.45	.340948	10.07	.659052	38
23	.331329	9.57	.989777	.47	.341552	10.05	.658448	37
24	.331903	9.58	.989749	.47	.342155	10.03	.657845	36
25	9.332478	9.55	9.989721	.47	9.342757	10.02	0.657243	35
26	.333051	9.55	.989693	.47	.343358	10.00	.656642	34
27	.333624	9.52	.989665	.47	.343958	10.00	.656042	33
28	.334195	9.53	.989637	.45	.344558	9.98	.655442	32
29	.334767	9.50	.989610	.47	.345157	9.97	.654843	31
30	9.335337	9.48	9.989582	.48	9.345755	9.97	0.654245	30
31	.335906	9.48	.989553	.47	.346353	9.93	.653647	29
32	.336475	9.47	.989525	.47	.346949	9.93	.653051	28
33	.337043	9.45	.989497	.47	.347545	9.93	.652455	27
34	.337610	9.43	.989469	.47	.348141	9.90	.651859	26
35	9.338176	9.43	9.989441	.47	9.348735	9.90	0.651265	25
36	.338742	9.42	.989413	.47	.349329	9.88	.650671	24
37	.339307	9.40	.989385	.48	.349922	9.87	.650078	23
38	.339871	9.38	.989356	.47	.350514	9.87	.649486	22
39	.340434	9.37	.989328	.47	.351106	9.85	.648894	21
40	9.340996	9.37	9.989300	.48	9.351697	9.83	0.648303	20
41	.341558	9.35	.989271	.47	.352287	9.82	.647713	19
42	.342119	9.33	.989243	.48	.352876	9.82	.647124	18
43	.342679	9.33	.989214	.47	.353465	9.80	.646535	17
44	.343239	9.30	.989186	.48	.354053	9.78	.645947	16
45	9.343797	9.30	9.989157	.48	9.354640	9.78	0.645360	15
46	.344355	9.28	.989128	.47	.355227	9.77	.644773	14
47	.344912	9.28	.989100	.48	.355813	9.75	.644187	13
48	.345469	9.25	.989071	.48	.356398	9.73	.643602	12
49	.346024	9.25	.989042	.47	.356982	9.73	.643018	11
50	9.346579	9.25	9.989014	.48	9.357566	9.72	0.642434	10
51	.347134	9.22	.988985	.48	.358149	9.70	.641851	9
52	.347687	9.22	.988956	.48	.358731	9.70	.641269	8
53	.348240	9.20	.988927	.48	.359313	9.67	.640687	7
54	.348792	9.18	.988898	.48	.359893	9.68	.640107	6
55	9.349343	9.17	9.988869	.48	9.360474	9.65	0.639526	5
56	.349893	9.17	.988840	.48	.361053	9.65	.638947	4
57	.350443	9.15	.988811	.48	.361632	9.63	.638368	3
58	.350992	9.13	.988782	.48	.362210	9.62	.637790	2
59	.351540	9.13	.988753	.48	.362787	9.62	.637213	1
60	9.352088		9.988724		9.363364		0.636636	0
	Cos.	D. 1″.	Sin.	D. 1″.	Cot.	D. 1″.	Tan.	M.

102° 77°

13° 16

M.	Sin.	D. 1″.	Cos.	D. 1″.	Tan.	D. 1″.	Cot.	
0	9.352088	9.12	9.988724	.48	9.363364	9.60	0.636636	60
1	.352635	9.10	.988695	.48	.363940	9.58	.636060	59
2	.353181	9.08	.988666	.50	.364515	9.58	.635485	58
3	.353726	9.08	.988636	.48	.365090	9.57	.634910	57
4	.354271	9.07	.988607	.48	.365664	9.55	.634336	56
5	9.354815	9.05	9.988578	.50	9.366237	9.55	0.633763	55
6	.355358	9.05	.988548	.48	.366810	9.53	.633190	54
7	.355901	9.03	.988519	.50	.367382	9.52	.632618	53
8	.356443	9.02	.988489	.48	.367953	9.52	.632047	52
9	.356984	9.00	.988460	.50	.368524	9.50	.631476	51
10	9.357524	9.00	9.988430	.48	9.369094	9.48	0.630906	50
11	.358064	8.98	.988401	.50	.369663	9.48	.630337	49
12	.358603	8.97	.988371	.48	.370232	9.45	.629768	48
13	.359141	8.95	.988342	.50	.370799	9.47	.629201	47
14	.359678	8.95	.988312	.50	.371367	9.43	.628633	46
15	9.360215	8.95	9.988282	.50	9.371933	9.43	0.628067	45
16	.360752	8.92	.988252	.48	.372499	9.42	.627501	44
17	.361287	8.92	.988223	.50	.373064	9.42	.626936	43
18	.361822	8.90	.988193	.50	.373629	9.40	.626371	42
19	.362356	8.88	.988163	.50	.374193	9.38	.625807	41
20	9.362889	8.88	9.988133	.50	9.374756	9.38	0.625244	40
21	.363422	8.87	.988103	.50	.375319	9.37	.624681	39
22	.363954	8.85	.988073	.50	.375881	9.35	.624119	38
23	.364485	8.85	.988043	.50	.376442	9.35	.623558	37
24	.365016	8.83	.988013	.50	.377003	9.33	.622997	36
25	9.365546	8.82	9.987983	.50	9.377563	9.32	0.622437	35
26	.366075	8.82	.987953	.52	.378122	9.32	.621878	34
27	.366604	8.78	.987922	.50	.378681	9.30	.621319	33
28	.367131	8.80	.987892	.50	.379239	9.30	.620761	32
29	.367659	8.77	.987862	.50	.379797	9.28	.620203	31
30	9.368185	8.77	9.987832	.52	9.380354	9.27	0.619646	30
31	.368711	8.75	.987801	.50	.380910	9.27	.619090	29
32	.369236	8.75	.987771	.52	.381466	9.23	.618534	28
33	.369761	8.73	.987740	.50	.382020	9.25	.617980	27
34	.370285	8.72	.987710	.52	.382575	9.23	.617425	26
35	9.370808	8.70	9.987679	.50	9.383129	9.22	0.616871	25
36	.371330	8.70	.987649	.52	.383682	9.20	.616318	24
37	.371852	8.68	.987618	.50	.384234	9.20	.615766	23
38	.372373	8.68	.987588	.52	.384786	9.18	.615214	22
39	.372894	8.67	.987557	.52	.385337	9.18	.614663	21
40	9.373414	8.65	9.987526	.50	9.385888	9.17	0.614112	20
41	.373933	8.65	.987496	.52	.386438	9.15	.613562	19
42	.374452	8.63	.987465	.52	.386987	9.15	.613013	18
43	.374970	8.62	.987434	.52	.387536	9.13	.612464	17
44	.375487	8.60	.987403	.52	.388084	9.12	.611916	16
45	9.376003	8.60	9.987372	.52	9.388631	9.12	0.611369	15
46	.376519	8.60	.987341	.52	.389178	9.10	.610822	14
47	.377035	8.57	.987310	.52	.389724	9.10	.610276	13
48	.377549	8.57	.987279	.52	.390270	9.08	.609730	12
49	.378063	8.57	.987248	.52	.390815	9.08	.609185	11
50	9.378577	8.53	9.987217	.52	9.391360	9.05	0.608640	10
51	.379089	8.53	.987186	.52	.391903	9.07	.608097	9
52	.379601	8.53	.987155	.52	.392447	9.03	.607553	8
53	.380113	8.52	.987124	.53	.392989	9.03	.607011	7
54	.380624	8.50	.987092	.52	.393531	9.03	.606469	6
55	9.381134	8.48	9.987061	.52	9.394073	9.02	0.605927	5
56	.381643	8.48	.987030	.53	.394614	9.00	.605386	4
57	.382152	8.48	.986998	.52	.395154	9.00	.604846	3
58	.382661	8.45	.986967	.52	.395694	8.98	.604306	2
59	.383168	8.45	.986936	.53	.396233	8.97	.603767	1
60	9.383675		9.986904		9.396771		0.603229	0
	Cos.	D. 1″.	Sin.	D. 1″.	Cot.	D. 1″.	Tan.	M.

103° 76

4° 165°

M.	Sin.	D. 1″.	Cos.	D. 1″.	Tan.	D. 1″.	Cot.	
0	9.383675	8.45	9.986904	.52	9.396771	8.97	0.603229	60
1	.384182	8.42	.986873	.53	.397309	8.95	.602691	59
2	.384687	8.42	.986841	.53	.397846	8.95	.602154	58
3	.385192	8.42	.986809	.52	.398383	8.93	.601617	57
4	.385697	8.40	.986778	.53	.398919	8.93	.601081	56
5	9.386201	8.38	9.986746	.53	9.399455	8.92	0.600545	55
6	.386704	8.38	.986714	.52	.399990	8.90	.600010	54
7	.387207	8.37	.986683	.53	.400524	8.90	.599476	53
8	.387709	8.35	.986651	.53	.401058	8.88	.598942	52
9	.388210	8.35	.986619	.53	.401591	8.88	.598409	51
10	9.388711	8.33	9.986587	.53	9.402124	8.87	0.597876	50
11	.389211	8.33	.986555	.53	.402656	8.85	.597344	49
12	.389711	8.32	.986523	.53	.403187	8.85	.596813	48
13	.390210	8.30	.986491	.53	.403718	8.85	.596282	47
14	.390708	8.30	.986459	.53	.404249	8.82	.595751	46
15	9.391206	8.28	9.986427	.53	9.404778	8.83	0.595222	45
16	.391703	8.27	.986395	.53	.405308	8.80	.594692	44
17	.392199	8.27	.986363	.53	.405836	8.80	.594164	43
18	.392695	8.27	.986331	.53	.406364	8.80	.593636	42
19	.393191	8.23	.986299	.55	.406892	8.78	.593108	41
20	9.393685	8.23	9.986266	.53	9.407419	8.77	0.592581	40
21	.394179	8.23	.986234	.53	.407945	8.77	.592055	39
22	.394673	8.22	.986202	.55	.408471	8.75	.591529	38
23	.395166	8.20	.986169	.53	.408996	8.75	.591004	37
24	.395658	8.20	.986137	.55	.409521	8.73	.590479	36
25	9.396150	8.18	9.986104	.53	9.410045	8.73	0.589955	35
26	.396641	8.18	.986072	.55	.410569	8.72	.589431	34
27	.397132	8.15	.986039	.53	.411092	8.72	.588908	33
28	.397621	8.17	.986007	.55	.411615	8.70	.588385	32
29	.398111	8.15	.985974	.53	.412137	8.68	.587863	31
30	9.398600	8.13	9.985942	.55	9.412658	8.68	0.587342	30
31	.399088	8.12	.985909	.55	.413179	8.67	.586821	29
32	.399575	8.12	.985876	.55	.413699	8.67	.586301	28
33	.400062	8.12	.985843	.53	.414219	8.65	.585781	27
34	.400549	8.10	.985811	.55	.414738	8.65	.585262	26
35	9.401035	8.08	9.985778	.55	9.415257	8.63	0.584743	25
36	.401520	8.08	.985745	.55	.415775	8.63	.584225	24
37	.402005	8.07	.985712	.55	.416293	8.62	.583707	23
38	.402489	8.05	.985679	.55	.416810	8.60	.583190	22
39	.402972	8.05	.985646	.55	.417326	8.60	.582674	21
40	9.403455	8.05	9.985613	.55	9.417842	8.60	0.582158	20
41	.403938	8.03	.985580	.55	.418358	8.58	.581642	19
42	.404420	8.02	.985547	.55	.418873	8.57	.581127	18
43	.404901	8.02	.985514	.57	.419387	8.57	.580613	17
44	.405382	8.00	.985480	.55	.419901	8.57	.580099	16
45	9.405862	7.98	9.985447	.55	9.420415	8.53	0.579585	15
46	.406341	7.98	.985414	.55	.420927	8.55	.579073	14
47	.406820	7.98	.985381	.57	.421440	8.53	.578560	13
48	.407299	7.97	.985347	.55	.421952	8.52	.578048	12
49	.407777	7.95	.985314	.57	.422463	8.52	.577537	11
50	9.408254	7.95	9.985280	.55	9.422974	8.50	0.577026	10
51	.408731	7.93	.985247	.57	.423484	8.48	.576516	9
52	.409207	7.92	.985213	.55	.423993	8.50	.576007	8
53	.409682	7.92	.985180	.57	.424503	8.47	.575497	7
54	.410157	7.92	.985146	.55	.425011	8.47	.574989	6
55	9.410632	7.90	9.985113	.57	9.425519	8.47	0.574481	5
56	.411106	7.88	.985079	.57	.426027	8.45	.573973	4
57	.411579	7.88	.985045	.57	.426534	8.45	.573466	3
58	.412052	7.87	.985011	.55	.427041	8.43	.572959	2
59	.412524	7.87	.984978	.57	.427547	8.42	.572453	1
60	9.412996		9.984944		9.428052		0.571948	0
	Cos.	D. 1″.	Sin.	D. 1″.	Cot.	D. 1″.	Tan.	M.

4° 75°

15° | 16

M.	Sin.	D. 1″.	Cos.	D. 1″.	Tan.	D. 1″.	Cot.
0	9.412996	7.85	9.984944	.57	9.428052	8.43	0.571948
1	.413467	7.85	.984910	.57	.428558	8.40	.571442
2	.413938	7.83	.984876	.57	.429062	8.40	.570938
3	.414408	7.83	.984842	.57	.429566	8.40	.570434
4	.414878	7.82	.984808	.57	.430070	8.38	.569930
5	9.415347	7.80	9.984774	.57	9.430573	8.37	0.569427
6	.415815	7.80	.984740	.57	.431075	8.37	.568925
7	.416283	7.80	.984706	.57	.431577	8.37	.568423
8	.416751	7.77	.984672	.57	.432079	8.35	.567921
9	.417217	7.78	.984638	.58	.432580	8.33	.567420
10	9.417684	7.77	9.984603	.57	9.433080	8.33	0.566920
11	.418150	7.75	.984569	.57	.433580	8.33	.566420
12	.418615	7.73	.984535	.58	.434080	8.32	.565920
13	.419079	7.75	.984500	.57	.434579	8.32	.565421
14	.419544	7.72	.984466	.57	.435078	8.30	.564922
15	9.420007	7.72	9.984432	.58	9.435576	8.28	0.564424
16	.420470	7.72	.984397	.57	.436073	8.28	.563927
17	.420933	7.70	.984363	.58	.436570	8.28	.563430
18	.421395	7.70	.984328	.57	.437067	8.27	.562933
19	.421857	7.68	.984294	.58	.437563	8.27	.562437
20	9.422318	7.67	9.984259	.58	9.438059	8.25	0.561941
21	.422778	7.67	.984224	.57	.438554	8.23	.561446
22	.423238	7.65	.984190	.58	.439048	8.25	.560952
23	.423697	7.65	.984155	.58	.439543	8.22	.560457
24	.424156	7.65	.984120	.58	.440036	8.22	.559964
25	9.424615	7.63	9.984085	.58	9.440529	8.22	0.559471
26	.425073	7.62	.984050	.58	.441022	8.20	.558978
27	.425530	7.62	.984015	.57	.441514	8.20	.558486
28	.425987	7.60	.983981	.58	.442006	8.18	.557994
29	.426443	7.60	.983946	.58	.442497	8.18	.557503
30	9.426899	7.58	9.983911	.60	9.442988	8.18	0.557012
31	.427354	7.58	.983875	.58	.443479	8.15	.556521
32	.427809	7.57	.983840	.58	.443968	8.17	.556032
33	.428263	7.57	.983805	.58	.444458	8.15	.555542
34	.428717	7.55	.983770	.58	.444947	8.13	.555053
35	9.429170	7.55	9.983735	.58	9.445435	8.13	0.554565
36	.429623	7.53	.983700	.60	.445923	8.13	.554077
37	.430075	7.53	.983664	.58	.446411	8.12	.553589
38	.430527	7.52	.983629	.58	.446898	8.10	.553102
39	.430978	7.52	.983594	.60	.447384	8.10	.552616
40	9.431429	7.50	9.983558	.58	9.447870	8.10	0.552130
41	.431879	7.50	.983523	.60	.448356	8.08	.551644
42	.432329	7.48	.983487	.58	.448841	8.08	.551159
43	.432778	7.47	.983452	.60	.449326	8.07	.550674
44	.433226	7.48	.983416	.58	.449810	8.07	.550190
45	9.433675	7.45	9.983381	.60	9.450294	8.05	0.549706
46	.434122	7.45	.983345	.60	.450777	8.05	.549223
47	.434569	7.45	.983309	.60	.451260	8.05	.548740
48	.435016	7.43	.983273	.58	.451743	8.03	.548257
49	.435462	7.43	.983238	.60	.452225	8.02	.547775
50	9.435908	7.42	9.983202	.60	9.452706	8.02	0.547294
51	.436353	7.42	.983166	.60	.453187	8.02	.546813
52	.436798	7.40	.983130	.60	.453668	8.00	.546332
53	.437242	7.40	.983094	.60	.454148	8.00	.545852
54	.437686	7.38	.983058	.60	.454628	7.98	.545372
55	9.438129	7.38	9.983022	.60	9.455107	7.98	0.544893
56	.438572	7.37	.982986	.60	.455586	7.97	.544414
57	.439014	7.37	.982950	.60	.456064	7.97	.543936
58	.439456	7.35	.982914	.60	.456542	7.95	.543458
59	.439897	7.35	.982878	.60	.457019	7.95	.542981
60	9.440338		9.982842		9.457496		0.542504
	Cos.	D. 1″.	Sin.	D. 1″.	Cot.	D. 1″.	Tan.

105°

16° 163°

M.	Sin.	D. 1″.	Cos.	D. 1″.	Tan.	D. 1″.	Cot.	
0	9.440338	7.33	9.982842	.62	9.457496	7.95	0.542504	60
1	.440778	7.33	.982805	.60	.457973	7.93	.542027	59
2	.441218	7.33	.982769	.60	.458449	7.93	.541551	58
3	.441658	7.30	.982733	.62	.458925	7.92	.541075	57
4	.442096	7.32	.982696	.60	.459400	7.92	.540600	56
5	9.442535	7.30	9.982660	.60	9.459875	7.90	0.540125	55
6	.442973	7.28	.982624	.62	.460349	7.90	.539651	54
7	.443410	7.28	.982587	.60	.460823	7.90	.539177	53
8	.443847	7.28	.982551	.62	.461297	7.88	.538703	52
9	.444284	7.27	.982514	.62	.461770	7.87	.538230	51
10	9.444720	7.25	9.982477	.60	9.462242	7.88	0.537758	50
11	.445155	7.25	.982441	.62	.462715	7.85	.537285	49
12	.445590	7.25	.982404	.62	.463186	7.87	.536814	48
13	.446025	7.23	.982367	.60	.463658	7.83	.536342	47
14	.446459	7.23	.982331	.62	.464128	7.85	.535872	46
15	9.446893	7.22	9.982294	.62	9.464599	7.83	0.535401	45
16	.447326	7.22	.982257	.62	.465069	7.83	.534931	44
17	.447759	7.20	.982220	.62	.465539	7.82	.534461	43
18	.448191	7.20	.982183	.62	.466008	7.82	.533992	42
19	.448623	7.18	.982146	.62	.466477	7.80	.533523	41
20	9.449054	7.18	9.982109	.62	9.466945	7.80	0.533055	40
21	.449485	7.17	.982072	.62	.467413	7.78	.532587	39
22	.449915	7.17	.982035	.62	.467880	7.78	.532120	38
23	.450345	7.17	.981998	.62	.468347	7.78	.531653	37
24	.450775	7.15	.981961	.62	.468814	7.77	.531186	36
25	9.451204	7.13	9.981924	.63	9.469280	7.77	0.530720	35
26	.451632	7.13	.981886	.62	.469746	7.75	.530254	34
27	.452060	7.13	.981849	.62	.470211	7.75	.529789	33
28	.452488	7.12	.981812	.63	.470676	7.75	.529324	32
29	.452915	7.12	.981774	.62	.471141	7.73	.528859	31
30	9.453342	7.10	9.981737	.62	9.471605	7.73	0.528395	30
31	.453768	7.10	.981700	.63	.472069	7.72	.527931	29
32	.454194	7.08	.981662	.62	.472532	7.72	.527468	28
33	.454619	7.08	.981625	.63	.472995	7.70	.527005	27
34	.455044	7.08	.981587	.63	.473457	7.70	.526543	26
35	9.455469	7.07	9.981549	.62	9.473919	7.70	0.526081	25
36	.455893	7.05	.981512	.63	.474381	7.68	.525619	24
37	.456316	7.05	.981474	.63	.474842	7.68	.525158	23
38	.456739	7.05	.981436	.62	.475303	7.67	.524697	22
39	.457162	7.03	.981399	.63	.475763	7.67	.524237	21
40	9.457584	7.03	9.981361	.63	9.476223	7.67	0.523777	20
41	.458006	7.02	.981323	.63	.476683	7.65	.523317	19
42	.458427	7.02	.981285	.63	.477142	7.65	.522858	18
43	.458848	7.00	.981247	.63	.477601	7.63	.522399	17
44	.459268	7.00	.981209	.63	.478059	7.63	.521941	16
45	9.459688	7.00	9.981171	.63	9.478517	7.63	0.521483	15
46	.460108	6.98	.981133	.63	.478975	7.62	.521025	14
47	.460527	6.98	.981095	.63	.479432	7.62	.520568	13
48	.460946	6.97	.981057	.63	.479889	7.60	.520111	12
49	.461364	6.97	.981019	.63	.480345	7.60	.519655	11
50	9.461782	6.95	9.980981	.65	9.480801	7.60	0.519199	10
51	.462199	6.95	.980942	.63	.481257	7.58	.518743	9
52	.462616	6.93	.980904	.63	.481712	7.58	.518288	8
53	.463032	6.93	.980866	.65	.482167	7.57	.517833	7
54	.463448	6.93	.980827	.63	.482621	7.57	.517379	6
55	9.463864	6.92	9.980789	.65	9.483075	7.57	0.516925	5
56	.464279	6.92	.980750	.63	.483529	7.55	.516471	4
57	.464694	6.90	.980712	.65	.483982	7.55	.516018	3
58	.465108	6.90	.980673	.63	.484435	7.53	.515565	2
59	.465522	6.88	.980635	.65	.484887	7.53	.515113	1
60	9.465935		9.980596		9.485339		0.514661	0
	Cos.	D. 1″.	Sin.	D. 1″.	Cot.	D. 1″.	Tan.	M.

06° 73°

17° 162

M.	Sin.	D. 1″.	Cos.	D. 1″.	Tan.	D. 1″.	Cot.	
0	9.465935	6.88	9.980596	.63	9.485339	7.53	0.514661	60
1	.466348	6.88	.980558	.65	.485791	7.52	.514209	59
2	.466761	6.87	.980519	.65	.486242	7.52	.513758	58
3	.467173	6.87	.980480	.63	.486693	7.50	.513307	57
4	.467585	6.85	.980442	.65	.487143	7.50	.512857	56
5	9.467996	6.85	9.980403	.65	9.487593	7.50	0.512407	55
6	.468407	6.83	.980364	.65	.488043	7.48	.511957	54
7	.468817	6.83	.980325	.65	.488492	7.48	.511508	53
8	.469227	6.83	.980286	.65	.488941	7.48	.511059	52
9	.469637	6.82	.980247	.65	.489390	7.47	.510610	51
10	9.470046	6.82	9.980208	.65	9.489838	7.47	0.510162	50
11	.470455	6.80	.980169	.65	.490286	7.45	.509714	49
12	.470863	6.80	.980130	.65	.490733	7.45	.509267	48
13	.471271	6.80	.980091	.65	.491180	7.45	.508820	47
14	.471679	6.78	.980052	.67	.491627	7.43	.508373	46
15	9.472086	6.77	9.980012	.65	9.492073	7.43	0.507927	45
16	.472492	6.77	.979973	.65	.492519	7.43	.507481	44
17	.472898	6.77	.979934	.65	.492965	7.42	.507035	43
18	.473304	6.77	.979895	.67	.493410	7.40	.506590	42
19	.473710	6.75	.979855	.65	.493854	7.42	.506146	41
20	9.474115	6.73	9.979816	.67	9.494299	7.40	0.505701	40
21	.474519	6.73	.979776	.65	.494743	7.38	.505257	39
22	.474923	6.73	.979737	.67	.495186	7.40	.504814	38
23	.475327	6.72	.979697	.65	.495630	7.38	.504370	37
24	.475730	6.72	.979658	.67	.496073	7.37	.503927	36
25	9.476133	6.72	9.979618	.65	9.496515	7.37	0.503485	35
26	.476536	6.70	.979579	.67	.496957	7.37	.503043	34
27	.476938	6.70	.979539	.67	.497399	7.37	.502601	33
28	.477340	6.68	.979499	.67	.497841	7.35	.502159	32
29	.477741	6.68	.979459	.65	.498282	7.33	.501718	31
30	9.478142	6.67	9.979420	.67	9.498722	7.35	0.501278	30
31	.478542	6.67	.979380	.67	.499163	7.33	.500837	29
32	.478942	6.67	.979340	.67	.499603	7.32	.500397	28
33	.479342	6.65	.979300	.67	.500042	7.32	.499958	27
34	.479741	6.65	.979260	.67	.500481	7.32	.499519	26
35	9.480140	6.65	9.979220	.67	9.500920	7.32	0.499080	25
36	.480539	6.63	.979180	.67	.501359	7.30	.498641	24
37	.480937	6.62	.979140	.67	.501797	7.30	.498203	23
38	.481334	6.62	.979100	.68	.502235	7.28	.497765	22
39	.481731	6.62	.979059	.67	.502672	7.28	.497328	21
40	9.482128	6.62	9.979019	.67	9.503109	7.28	0.496891	20
41	.482525	6.60	.978979	.67	.503546	7.27	.496454	19
42	.482921	6.58	.978939	.68	.503982	7.27	.496018	18
43	.483316	6.60	.978898	.67	.504418	7.27	.495582	17
44	.483712	6.58	.978858	.68	.504854	7.25	.495146	16
45	9.484107	6.57	9.978817	.67	9.505289	7.25	0.494711	15
46	.484501	6.57	.978777	.67	.505724	7.25	.494276	14
47	.484895	6.57	.978737	.68	.506159	7.23	.493841	13
48	.485289	6.55	.978696	.68	.506593	7.23	.493407	12
49	.485682	6.55	.978655	.67	.507027	7.22	.492973	11
50	9.486075	6.53	9.978615	.68	9.507460	7.22	0.492540	10
51	.486467	6.55	.978574	.68	.507893	7.22	.492107	9
52	.486860	6.52	.978533	.67	.508326	7.22	.491674	8
53	.487251	6.53	.978493	.68	.508759	7.20	.491241	7
54	.487643	6.52	.978452	.68	.509191	7.18	.490809	6
55	9.488034	6.50	9.978411	.68	9.509622	7.20	0.490378	5
56	.488424	6.50	.978370	.68	.510054	7.18	.489946	4
57	.488814	6.50	.978329	.68	.510485	7.18	.489515	3
58	.489204	6.48	.978288	.68	.510916	7.17	.489084	2
59	.489593	6.48	.978247	.68	.511346	7.17	.488654	1
60	9.489982		9.978206		9.511776		0.488224	0
	Cos.	D. 1″.	Sin.	D. 1″.	Cot.	D. 1″.	Tan.	M.

107° 72

18° 161°

M.	Sin.	D. 1″.	Cos.	D. 1″.	Tan.	D. 1″.	Cot.	
0	9.489982	6.48	9.978206	.68	9.511776	7.17	0.488224	60
1	.490371	6.47	.978165	.68	.512206	7.15	.487794	59
2	.490759	6.47	.978124	.68	.512635	7.15	.487365	58
3	.491147	6.47	.978083	.68	.513064	7.15	.486936	57
4	.491535	6.45	.978042	.68	.513493	7.13	.486507	56
5	9.491922	6.43	9.978001	.70	9.513921	7.13	0.486079	55
6	.492308	6.45	.977959	.68	.514349	7.13	.485651	54
7	.492695	6.43	.977918	.68	.514777	7.12	.485223	53
8	.493081	6.42	.977877	.70	.515204	7.12	.484796	52
9	.493466	6.42	.977835	.68	.515631	7.10	.484369	51
10	9.493851	6.42	9.977794	.70	9.516057	7.12	0.483943	50
11	.494236	6.42	.977752	.68	.516484	7.10	.483516	49
12	.494621	6.40	.977711	.70	.516910	7.08	.483090	48
13	.495005	6.38	.977669	.68	.517335	7.10	.482665	47
14	.495388	6.40	.977628	.70	.517761	7.08	.482239	46
15	9.495772	6.37	9.977586	.70	9.518186	7.07	0.481814	45
16	.496154	6.38	.977544	.68	.518610	7.07	.481390	44
17	.496537	6.37	.977503	.70	.519034	7.07	.480966	43
18	.496919	6.37	.977461	.70	.519458	7.07	.480542	42
19	.497301	6.35	.977419	.70	.519882	7.05	.480118	41
20	9.497682	6.37	9.977377	.70	9.520305	7.05	0.479695	40
21	.498064	6.33	.977335	.70	.520728	7.05	.479272	39
22	.498444	6.35	.977293	.70	.521151	7.03	.478849	38
23	.498825	6.32	.977251	.70	.521573	7.03	.478427	37
24	.499204	6.33	.977209	.70	.521995	7.03	.478005	36
25	9.499584	6.32	9.977167	.70	9.522417	7.02	0.477583	35
26	.499963	6.32	.977125	.70	.522838	7.02	.477162	34
27	.500342	6.32	.977083	.70	.523259	7.02	.476741	33
28	.500721	6.30	.977041	.70	.523680	7.00	.476320	32
29	.501099	6.28	.976999	.70	.524100	7.00	.475900	31
30	9.501476	6.30	9.976957	.72	9.524520	7.00	0.475480	30
31	.501854	6.28	.976914	.70	.524940	6.98	.475060	29
32	.502231	6.27	.976872	.70	.525359	6.98	.474641	28
33	.502607	6.28	.976830	.72	.525778	6.98	.474222	27
34	.502984	6.27	.976787	.70	.526197	6.97	.473803	26
35	9.503360	6.25	9.976745	.72	9.526615	6.97	0.473385	25
36	.503735	6.25	.976702	.70	.527033	6.97	.472967	24
37	.504110	6.25	.976660	.72	.527451	6.95	.472549	23
38	.504485	6.25	.976617	.72	.527868	6.95	.472132	22
39	.504860	6.23	.976574	.70	.528285	6.95	.471715	21
40	9.505234	6.23	9.976532	.72	9.528702	6.95	0.471298	20
41	.505608	6.22	.976489	.72	.529119	6.93	.470881	19
42	.505981	6.22	.976446	.70	.529535	6.93	.470465	18
43	.506354	6.22	.976404	.72	.529951	6.92	.470049	17
44	.506727	6.20	.976361	.72	.530366	6.92	.469634	16
45	9.507099	6.20	9.976318	.72	9.530781	6.92	0.469219	15
46	.507471	6.20	.976275	.72	.531196	6.92	.468804	14
47	.507843	6.18	.976232	.72	.531611	6.90	.468389	13
48	.508214	6.18	.976189	.72	.532025	6.90	.467975	12
49	.508585	6.18	.976146	.72	.532439	6.90	.467561	11
50	9.508956	6.17	9.976103	.72	9.532853	6.88	0.467147	10
51	.509326	6.17	.976060	.72	.533266	6.88	.466734	9
52	.509696	6.15	.976017	.72	.533679	6.88	.466321	8
53	.510065	6.15	.975974	.73	.534092	6.87	.465908	7
54	.510434	6.15	.975930	.72	.534504	6.87	.465496	6
55	9.510803	6.15	9.975887	.72	9.534916	6.87	0.465084	5
56	.511172	6.13	.975844	.73	.535328	6.85	.464672	4
57	.511540	6.12	.975800	.72	.535739	6.85	.464261	3
58	.511907	6.13	.975757	.72	.536150	6.85	.463850	2
59	.512275	6.12	.975714	.73	.536561	6.85	.463439	1
60	9.512642		9.975670		9.536972		0.463028	0
	Cos.	D. 1″.	Sin.	D. 1″.	Cot.	D. 1″.	Tan.	M.

8° 71°

19°

M.	Sin.	D. 1″.	Cos.	D. 1″.	Tan.	D. 1″.	Cot.
0	9.512642	6.12	9.975670	.72	9.536972	6.83	0.463028
1	.513009	6.10	.975627	.73	.537382	6.83	.462618
2	.513375	6.10	.975583	.73	.537792	6.83	.462208
3	.513741	6.10	.975539	.72	.538202	6.82	.461798
4	.514107	6.08	.975496	.73	.538611	6.82	.461389
5	9.514472	6.08	9.975452	.73	9.539020	6.82	0.460980
6	.514837	6.08	.975408	.72	.539429	6.80	.460571
7	.515202	6.07	.975365	.73	.539837	6.80	.460163
8	.515566	6.07	.975321	.73	.540245	6.80	.459755
9	.515930	6.07	.975277	.73	.540653	6.80	.459347
10	9.516294	6.05	9.975233	.73	9.541061	6.78	0.458939
11	.516657	6.05	.975189	.73	.541468	6.78	.458532
12	.517020	6.03	.975145	.73	.541875	6.77	.458125
13	.517382	6.05	.975101	.73	.542281	6.78	.457719
14	.517745	6.03	.975057	.73	.542688	6.77	.457312
15	9.518107	6.02	9.975013	.73	9.543094	6.75	0.456906
16	.518468	6.02	.974969	.73	.543499	6.77	.456501
17	.518829	6.02	.974925	.75	.543905	6.75	.456095
18	.519190	6.02	.974880	.73	.544310	6.75	.455690
19	.519551	6.00	.974836	.73	.544715	6.73	.455285
20	9.519911	6.00	9.974792	.73	9.545119	6.75	0.454881
21	.520271	6.00	.974748	.75	.545524	6.73	.454476
22	.520631	5.98	.974703	.73	.545928	6.72	.454072
23	.520990	5.98	.974659	.75	.546331	6.73	.453669
24	.521349	5.97	.974614	.73	.546735	6.72	.453265
25	9.521707	5.98	9.974570	.75	9.547138	6.70	0.452862
26	.522066	5.97	.974525	.73	.547540	6.72	.452460
27	.522424	5.95	.974481	.75	.547943	6.70	.452057
28	.522781	5.95	.974436	.75	.548345	6.70	.451655
29	.523138	5.95	.974391	.73	.548747	6.70	.451253
30	9.523495	5.95	9.974347	.75	9.549149	6.68	0.450851
31	.523852	5.93	.974302	.75	.549550	6.68	.450450
32	.524208	5.93	.974257	.75	.549951	6.68	.450049
33	.524564	5.93	.974212	.75	.550352	6.67	.449648
34	.524920	5.92	.974167	.75	.550752	6.68	.449248
35	9.525275	5.92	9.974122	.75	9.551153	6.65	0.448847
36	.525630	5.90	.974077	.75	.551552	6.67	.448448
37	.525984	5.92	.974032	.75	.551952	6.65	.448048
38	.526339	5.90	.973987	.75	.552351	6.65	.447649
39	.526693	5.88	.973942	.75	.552750	6.65	.447250
40	9.527046	5.90	9.973897	.75	9.553149	6.65	0.446851
41	.527400	5.88	.973852	.75	.553548	6.63	.446452
42	.527753	5.87	.973807	.77	.553946	6.63	.446054
43	.528105	5.88	.973761	.75	.554344	6.62	.445656
44	.528458	5.87	.973716	.75	.554741	6.63	.445259
45	9.528810	5.85	9.973671	.77	9.555139	6.62	0.444861
46	.529161	5.87	.973625	.75	.555536	6.62	.444464
47	.529513	5.85	.973580	.75	.555933	6.60	.444067
48	.529864	5.85	.973535	.77	.556329	6.60	.443671
49	.530215	5.83	.973489	.75	.556725	6.60	.443275
50	9.530565	5.83	9.973444	.77	9.557121	6.60	0.442879
51	.530915	5.83	.973398	.77	.557517	6.60	.442483
52	.531265	5.82	.973352	.75	.557913	6.58	.442087
53	.531614	5.82	.973307	.77	.558308	6.58	.441692
54	.531963	5.82	.973261	.77	.558703	6.57	.441297
55	9.532312	5.82	9.973215	.77	9.559097	6.57	0.440903
56	.532661	5.80	.973169	.75	.559491	6.57	.440509
57	.533009	5.80	.973124	.77	.559885	6.57	.440115
58	.533357	5.78	.973078	.77	.560279	6.57	.439721
59	.533704	5.80	.973032	.77	.560673	6.55	.439327
60	9.534052		9.972986		9.561066		0.438934
	Cos.	D. 1″.	Sin.	D. 1″.	Cot.	D. 1″.	Tan.

70°

20° 159°

M.	Sin.	D. 1″.	Cos.	D. 1″.	Tan.	D. 1″.	Cot.	
0	9.534052	5.78	9.972986	.77	9.561066	6.55	0.438934	60
1	.534399	5.77	.972940	.77	.561459	6.53	.438541	59
2	.534745	5.78	.972894	.77	.561851	6.55	.438149	58
3	.535092	5.77	.972848	.77	.562244	6.53	.437756	57
4	.535438	5.75	.972802	.78	.562636	6.53	.437364	56
5	9.535783	5.77	9.972755	.77	9.563028	6.52	0.436972	55
6	.536129	5.75	.972709	.77	.563419	6.53	.436581	54
7	.536474	5.73	.972663	.77	.563811	6.52	.436189	53
8	.536818	5.75	.972617	.78	.564202	6.52	.435798	52
9	.537163	5.73	.972570	.77	.564593	6.50	.435407	51
10	9.537507	5.73	9.972524	.77	9.564983	6.50	0.435017	50
11	.537851	5.72	.972478	.78	.565373	6.50	.434627	49
12	.538194	5.73	.972431	.77	.565763	6.50	.434237	48
13	.538538	5.70	.972385	.78	.566153	6.48	.433847	47
14	.538880	5.72	.972338	.78	.566542	6.50	.433458	46
15	9.539223	5.70	9.972291	.77	9.566932	6.47	0.433068	45
16	.539565	5.70	.972245	.78	.567320	6.48	.432680	44
17	.539907	5.70	.972198	.78	.567709	6.48	.432291	43
18	.540249	5.68	.972151	.77	.568098	6.47	.431902	42
19	.540590	5.68	.972105	.78	.568486	6.45	.431514	41
20	9.540931	5.68	9.972058	.78	9.568873	6.47	0.431127	40
21	.541272	5.68	.972011	.78	.569261	6.45	.430739	39
22	.541613	5.67	.971964	.78	.569648	6.45	.430352	38
23	.541953	5.67	.971917	.78	.570035	6.45	.429965	37
24	.542293	5.65	.971870	.78	.570422	6.45	.429578	36
25	9.542632	5.65	9.971823	.78	9.570809	6.43	0.429191	35
26	.542971	5.65	.971776	.78	.571195	6.43	.428805	34
27	.543310	5.65	.971729	.78	.571581	6.43	.428419	33
28	.543649	5.63	.971682	.78	.571967	6.42	.428033	32
29	.543987	5.63	.971635	.78	.572352	6.43	.427648	31
30	9.544325	5.63	9.971588	.80	9.572738	6.42	0.427262	30
31	.544663	5.62	.971540	.78	.573123	6.40	.426877	29
32	.545000	5.63	.971493	.78	.573507	6.42	.426493	28
33	.545338	5.60	.971446	.80	.573892	6.40	.426108	27
34	.545674	5.62	.971398	.78	.574276	6.40	.425724	26
35	9.546011	5.60	9.971351	.80	9.574660	6.40	0.425340	25
36	.546347	5.60	.971303	.78	.575044	6.38	.424956	24
37	.546683	5.60	.971256	.80	.575427	6.38	.424573	23
38	.547019	5.58	.971208	.78	.575810	6.38	.424190	22
39	.547354	5.58	.971161	.80	.576193	6.38	.423807	21
40	9.547689	5.58	9.971113	.78	9.576576	6.38	0.423424	20
41	.548024	5.58	.971066	.80	.576959	6.37	.423041	19
42	.548359	5.57	.971018	.80	.577341	6.37	.422659	18
43	.548693	5.57	.970970	.80	.577723	6.35	.422277	17
44	.549027	5.55	.970922	.80	.578104	6.37	.421896	16
45	9.549360	5.55	9.970874	.78	9.578486	6.35	0.421514	15
46	.549693	5.55	.970827	.80	.578867	6.35	.421133	14
47	.550026	5.55	.970779	.80	.579248	6.35	.420752	13
48	.550359	5.55	.970731	.80	.579629	6.33	.420371	12
49	.550692	5.53	.970683	.80	.580009	6.33	.419991	11
50	9.551024	5.53	9.970635	.82	9.580389	6.33	0.419611	10
51	.551356	5.52	.970586	.80	.580769	6.33	.419231	9
52	.551687	5.52	.970538	.80	.581149	6.32	.418851	8
53	.552018	5.52	.970490	.80	.581528	6.32	.418472	7
54	.552349	5.52	.970442	.80	.581907	6.32	.418093	6
55	9.552680	5.50	9.970394	.82	9.582286	6.32	0.417714	5
56	.553010	5.52	.970345	.80	.582665	6.32	.417335	4
57	.553341	5.48	.970297	.80	.583044	6.30	.416956	3
58	.553670	5.50	.970249	.82	.583422	6.30	.416578	2
59	.554000	5.48	.970200	.80	.583800	6.28	.416200	1
60	9.554329		9.970152		9.584177		0.415823	0
	Cos.	D. 1″.	Sin.	D. 1″.	Cot.	D. 1″.	Tan.	M.

110° 69°

21° 15

M.	Sin.	D. 1".	Cos.	D. 1".	Tan.	D. 1".	Cot.	M.
0	9.554329	5.48	9.970152	.82	9.584177	6.30	0.415823	60
1	.554658	5.48	.970103	.80	.584555	6.28	.415445	59
2	.554987	5.47	.970055	.82	.584932	6.28	.415068	58
3	.555315	5.47	.970006	.82	.585309	6.28	.414691	57
4	.555643	5.47	.969957	.80	.585686	6.27	.414314	56
5	9.555971	5.47	9.969909	.82	9.586062	6.28	0.413938	55
6	.556299	5.45	.969860	.82	.586439	6.27	.413561	54
7	.556626	5.45	.969811	.82	.586815	6.25	.413185	53
8	.556953	5.45	.969762	.80	.587190	6.27	.412810	52
9	.557280	5.43	.969714	.82	.587566	6.25	.412434	51
10	9.557606	5.43	9.969665	.82	9.587941	6.25	0.412059	50
11	.557932	5.43	.969616	.82	.588316	6.25	.411684	49
12	.558258	5.42	.969567	.82	.588691	6.25	.411309	48
13	.558583	5.43	.969518	.82	.589066	6.23	.410934	47
14	.558909	5.42	.969469	.82	.589440	6.23	.410560	46
15	9.559234	5.40	9.969420	.83	9.589814	6.23	0.410186	45
16	.559558	5.42	.969370	.82	.590188	6.23	.409812	44
17	.559883	5.40	.969321	.82	.590562	6.22	.409438	43
18	.560207	5.40	.969272	.82	.590935	6.22	.409065	42
19	.560531	5.40	.969223	.83	.591308	6.22	.408692	41
20	9.560855	5.38	9.969173	.82	9.591681	6.22	0.408319	40
21	.561178	5.38	.969124	.82	.592054	6.20	.407946	39
22	.561501	5.38	.969075	.83	.592426	6.22	.407574	38
23	.561824	5.37	.969025	.82	.592799	6.20	.407201	37
24	.562146	5.37	.968976	.83	.593171	6.18	.406829	36
25	9.562468	5.37	9.968926	.82	9.593542	6.20	0.406458	35
26	.562790	5.37	.968877	.83	.593914	6.18	.406086	34
27	.563112	5.35	.968827	.83	.594285	6.18	.405715	33
28	.563433	5.37	.968777	.82	.594656	6.18	.405344	32
29	.563755	5.33	.968728	.83	.595027	6.18	.404973	31
30	9.564075	5.35	9.968678	.83	9.595398	6.17	0.404602	30
31	.564396	5.33	.968628	.83	.595768	6.17	.404232	29
32	.564716	5.33	.968578	.83	.596138	6.17	.403862	28
33	.565036	5.33	.968528	.82	.596508	6.17	.403492	27
34	.565356	5.33	.968479	.83	.596878	6.15	.403122	26
35	9.565676	5.32	9.968429	.83	9.597247	6.15	0.402753	25
36	.565995	5.32	.968379	.83	.597616	6.15	.402384	24
37	.566314	5.30	.968329	.85	.597985	6.15	.402015	23
38	.566632	5.32	.968278	.83	.598354	6.13	.401646	22
39	.566951	5.30	.968228	.83	.598722	6.15	.401278	21
40	9.567269	5.30	9.968178	.83	9.599091	6.13	0.400909	20
41	.567587	5.28	.968128	.83	.599459	6.13	.400541	19
42	.567904	5.30	.968078	.85	.599827	6.12	.400173	18
43	.568222	5.28	.968027	.83	.600194	6.13	.399806	17
44	.568539	5.28	.967977	.83	.600562	6.12	.399438	16
45	9.568856	5.27	9.967927	.85	9.600929	6.12	0.399071	15
46	.569172	5.27	.967876	.83	.601296	6.12	.398704	14
47	.569488	5.27	.967826	.85	.601663	6.10	.398337	13
48	.569804	5.27	.967775	.83	.602029	6.10	.397971	12
49	.570120	5.25	.967725	.85	.602395	6.10	.397605	11
50	9.570435	5.27	9.967674	.83	9.602761	6.10	0.397239	10
51	.570751	5.25	.967624	.85	.603127	6.10	.396873	9
52	.571066	5.23	.967573	.85	.603493	6.08	.396507	8
53	.571380	5.25	.967522	.85	.603858	6.08	.396142	7
54	.571695	5.23	.967471	.83	.604223	6.08	.395777	6
55	9.572009	5.23	9.967421	.85	9.604588	6.08	0.395412	5
56	.572323	5.22	.967370	.85	.604953	6.07	.395047	4
57	.572636	5.23	.967319	.85	.605317	6.08	.394683	3
58	.572950	5.22	.967268	.85	.605682	6.07	.394318	2
59	.573263	5.20	.967217	.85	.606046	6.07	.393954	1
60	9.573575		9.967166		9.606410		0.393590	0
	Cos.	D. 1".	Sin.	D. 1".	Cot.	D. 1".	Tan.	M.

111° 6

22° 156°

M.	Sin.	D. 1″.	Cos.	D. 1″.	Tan.	D. 1″.	Cot.	
0	9.573575		9.967166		9.606410		0.393590	60
1	.573888	5.22	.967115	.85	.606773	6.05	.393227	59
2	.574200	5.20	.967064	.85	.607137	6.07	.392863	58
3	.574512	5.20	.967013	.85	.607500	6.05	.392500	57
4	.574824	5.20	.966961	.87	.607863	6.05	.392137	56
5	9.575136	5.20	9.966910	.85	9.608225	6.03	0.391775	55
6	.575447	5.18	.966859	.85	.608588	6.05	.391412	54
7	.575758	5.18	.966808	.85	.608950	6.03	.391050	53
8	.576069	5.18	.966756	.87	.609312	6.03	.390688	52
9	.576379	5.17	.966705	.85	.609674	6.03	.390326	51
10	9.576689	5.17	9.966653	.87	9.610036	6.03	0.389964	50
11	.576999	5.17	.966602	.85	.610397	6.02	.389603	49
12	.577309	5.17	.966550	.87	.610759	6.03	.389241	48
13	.577618	5.15	.966499	.85	.611120	6.02	.388880	47
14	.577927	5.15	.966447	.87	.611480	6.00	.388520	46
15	9.578236	5.15	9.966395	.87	9.611841	6.02	0.388159	45
16	.578545	5.15	.966344	.85	.612201	6.00	.387799	44
17	.578853	5.13	.966292	.87	.612561	6.00	.387439	43
18	.579162	5.15	.966240	.87	.612921	6.00	.387079	42
19	.579470	5.13	.966188	.87	.613281	6.00	.386719	41
20	9.579777	5.12	9.966136	.87	9.613641	6.00	0.386359	40
21	.580085	5.13	.966085	.85	.614000	5.98	.386000	39
22	.580392	5.12	.966033	.87	.614359	5.98	.385641	38
23	.580699	5.12	.965981	.87	.614718	5.98	.385282	37
24	.581005	5.10	.965929	.87	.615077	5.98	.384923	36
25	9.581312	5.12	9.965876	.88	9.615435	5.97	0.384565	35
26	.581618	5.10	.965824	.87	.615793	5.97	.384207	34
27	.581924	5.10	.965772	.87	.616151	5.97	.383849	33
28	.582229	5.08	.965720	.87	.616509	5.97	.383491	32
29	.582535	5.10	.965668	.87	.616867	5.97	.383133	31
30	9.582840	5.08	9.965615	.88	9.617224	5.95	0.382776	30
31	.583145	5.08	.965563	.87	.617582	5.97	.382418	29
32	.583449	5.07	.965511	.87	.617939	5.95	.382061	28
33	.583754	5.08	.965458	.88	.618295	5.93	.381705	27
34	.584058	5.07	.965406	.87	.618652	5.95	.381348	26
35	9.584361	5.05	9.965353	.88	9.619008	5.93	0.380992	25
36	.584665	5.07	.965301	.87	.619364	5.93	.380636	24
37	.584968	5.05	.965248	.88	.619720	5.93	.380280	23
38	.585272	5.07	.965195	.88	.620076	5.93	.379924	22
39	.585574	5.03	.965143	.87	.620432	5.93	.379568	21
40	9.585877	5.05	9.965090	.88	9.620787	5.92	0.379213	20
41	.586179	5.03	.965037	.88	.621142	5.92	.378858	19
42	.586482	5.05	.964984	.88	.621497	5.92	.378503	18
43	.586783	5.02	.964931	.88	.621852	5.92	.378148	17
44	.587085	5.03	.964879	.87	.622207	5.92	.377793	16
45	9.587386	5.02	9.964826	.88	9.622561	5.90	0.377439	15
46	.587688	5.03	.964773	.88	.622915	5.90	.377085	14
47	.587989	5.02	.964720	.88	.623269	5.90	.376731	13
48	.588289	5.00	.964666	.90	.623623	5.90	.376377	12
49	.588590	5.02	.964613	.88	.623976	5.88	.376024	11
50	9.588890	5.00	9.964560	.88	9.624330	5.90	0.375670	10
51	.589190	5.00	.964507	.88	.624683	5.88	.375317	9
52	.589489	4.98	.964454	.88	.625036	5.88	.374964	8
53	.589789	5.00	.964400	.90	.625388	5.87	.374612	7
54	.590088	4.98	.964347	.88	.625741	5.88	.374259	6
55	9.590387	4.98	9.964294	.88	9.626093	5.87	0.373907	5
56	.590686	4.98	.964240	.90	.626445	5.87	.373555	4
57	.590984	4.97	.964187	.88	.626797	5.87	.373203	3
58	.591282	4.97	.964133	.90	.627149	5.87	.372851	2
59	.591580	4.97	.964080	.88	.627501	5.87	.372499	1
60	9.591878	4.97	9.964026	.90	9.627852	5.85	0.372148	0
	Cos.	D. 1″.	Sin.	D. 1″.	Cot.	D. 1″.	Tan.	M.

2° 67°

23° 156°

M.	Sin.	D. 1″.	Cos.	D. 1″.	Tan.	D. 1″.	Cot.	
0	9.591878	4.97	9.964026	.90	9.627852	5.85	0.372148	60
1	.592176	4.95	.963972	.88	.628203	5.85	.371797	59
2	.592473	4.95	.963919	.90	.628554	5.85	.371446	58
3	.592770	4.95	.963865	.90	.628905	5.83	.371095	57
4	.593067	4.93	.963811	.90	.629255	5.85	.370745	56
5	9.593363	4.93	9.963757	.88	9.629606	5.83	0.370394	55
6	.593659	4.93	.963704	.90	.629956	5.83	.370044	54
7	.593955	4.93	.963650	.90	.630306	5.83	.369694	53
8	.594251	4.93	.963596	.90	.630656	5.82	.369344	52
9	.594547	4.92	.963542	.90	.631005	5.83	.368995	51
10	9.594842	4.92	9.963488	.90	9.631355	5.82	0.368645	50
11	.595137	4.92	.963434	.92	.631704	5.82	.368296	49
12	.595432	4.92	.963379	.90	.632053	5.82	.367947	48
13	.595727	4.90	.963325	.90	.632402	5.80	.367598	47
14	.596021	4.90	.963271	.90	.632750	5.82	.367250	46
15	9.596315	4.90	9.963217	.90	9.633099	5.80	0.366901	45
16	.596609	4.90	.963163	.92	.633447	5.80	.366553	44
17	.596903	4.88	.963108	.90	.633795	5.80	.366205	43
18	.597196	4.90	.963054	.92	.634143	5.78	.365857	42
19	.597490	4.88	.962999	.90	.634490	5.80	.365510	41
20	9.597783	4.87	9.962945	.92	9.634838	5.78	0.365162	40
21	.598075	4.88	.962890	.90	.635185	5.78	.364815	39
22	.598368	4.87	.962836	.92	.635532	5.78	.364468	38
23	.598660	4.87	.962781	.90	.635879	5.78	.364121	37
24	.598952	4.87	.962727	.92	.636226	5.77	.363774	36
25	9.599244	4.87	9.962672	.92	9.636572	5.78	0.363428	35
26	.599536	4.85	.962617	.92	.636919	5.77	.363081	34
27	.599827	4.85	.962562	.90	.637265	5.77	.362735	33
28	.600118	4.85	.962508	.92	.637611	5.75	.362389	32
29	.600409	4.85	.962453	.92	.637956	5.77	.362044	31
30	9.600700	4.83	9.962398	.92	9.638302	5.75	0.361698	30
31	.600990	4.83	.962343	.92	.638647	5.75	.361353	29
32	.601280	4.83	.962288	.92	.638992	5.75	.361008	28
33	.601570	4.83	.962233	.92	.639337	5.75	.360663	27
34	.601860	4.83	.962178	.92	.639682	5.75	.360318	26
35	9.602150	4.82	9.962123	.93	9.640027	5.73	0.359973	25
36	.602439	4.82	.962067	.92	.640371	5.75	.359629	24
37	.602728	4.82	.962012	.92	.640716	5.73	.359284	23
38	.603017	4.80	.961957	.92	.641060	5.73	.358940	22
39	.603305	4.82	.961902	.93	.641404	5.72	.358596	21
40	9.603594	4.80	9.961846	.92	9.641747	5.73	0.358253	20
41	.603882	4.80	.961791	.93	.642091	5.72	.357909	19
42	.604170	4.78	.961735	.92	.642434	5.72	.357566	18
43	.604457	4.80	.961680	.93	.642777	5.72	.357223	17
44	.604745	4.78	.961624	.92	.643120	5.72	.356880	16
45	9.605032	4.78	9.961569	.93	9.643463	5.72	0.356537	15
46	.605319	4.78	.961513	.92	.643806	5.70	.356194	14
47	.605606	4.77	.961458	.93	.644148	5.70	.355852	13
48	.605892	4.78	.961402	.93	.644490	5.70	.355510	12
49	.606179	4.77	.961346	.93	.644832	5.70	.355168	11
50	9.606465	4.77	9.961290	.92	9.645174	5.70	0.354826	10
51	.606751	4.75	.961235	.93	.645516	5.68	.354484	9
52	.607036	4.77	.961179	.93	.645857	5.70	.354143	8
53	.607322	4.75	.961123	.93	.646199	5.68	.353801	7
54	.607607	4.75	.961067	.93	.646540	5.68	.353460	6
55	9.607892	4.75	9.961011	.93	9.646881	5.68	0.353119	5
56	.608177	4.73	.960955	.93	.647222	5.67	.352778	4
57	.608461	4.73	.960899	.93	.647562	5.68	.352438	3
58	.608745	4.73	.960843	.95	.647903	5.67	.352097	2
59	.609029	4.73	.960786	.93	.648243	5.67	.351757	1
60	9.609313		9.960730		9.648583		0.351417	0
	Cos.	D. 1″.	Sin.	D. 1″.	Cot.	D. 1″.	Tan.	M.

131° 66°

4° 155°

M.	Sin.	D. 1".	Cos.	D. 1".	Tan.	D. 1".	Cot.	
0	9.609313	4.73	9.960730	.93	9.648583	5.67	0.351417	60
1	.609597	4.72	.960674	.93	.648923	5.67	.351077	59
2	.609880	4.73	.960618	.95	.649263	5.65	.350737	58
3	.610164	4.72	.960561	.93	.649602	5.67	.350398	57
4	.610447	4.70	.960505	.95	.649942	5.65	.350058	56
5	9.610729	4.72	9.960448	.93	9.650281	5.65	0.349719	55
6	.611012	4.70	.960392	.95	.650620	5.65	.349380	54
7	.611294	4.70	.960335	.93	.650959	5.63	.349041	53
8	.611576	4.70	.960279	.95	.651297	5.65	.348703	52
9	.611858	4.70	.960222	.95	.651636	5.63	.348364	51
0	9.612140	4.68	9.960165	.93	9.651974	5.63	0.348026	50
1	.612421	4.68	.960109	.95	.652312	5.63	.347688	49
2	.612702	4.68	.960052	.95	.652650	5.63	.347350	48
3	.612983	4.68	.959995	.95	.652988	5.63	.347012	47
4	.613264	4.68	.959938	.93	.653326	5.62	.346674	46
5	9.613545	4.67	9.959882	.95	9.653663	5.62	0.346337	45
6	.613825	4.67	.959825	.95	.654000	5.62	.346000	44
7	.614105	4.67	.959768	.95	.654337	5.62	.345663	43
8	.614385	4.67	.959711	.95	.654674	5.62	.345326	42
9	.614665	4.65	.959654	.97	.655011	5.62	.344989	41
0	9.614944	4.65	9.959596	.95	9.655348	5.60	0.344652	40
1	.615223	4.65	.959539	.95	.655684	5.60	.344316	39
2	.615502	4.65	.959482	.95	.656020	5.60	.343980	38
3	.615781	4.65	.959425	.95	.656356	5.60	.343644	37
4	.616060	4.63	.959368	.97	.656692	5.60	.343308	36
5	9.616338	4.63	9.959310	.95	9.657028	5.60	0.342972	35
6	.616616	4.63	.959253	.97	.657364	5.58	.342636	34
7	.616894	4.63	.959195	.95	.657699	5.58	.342301	33
8	.617172	4.63	.959138	.97	.658034	5.58	.341966	32
9	.617450	4.62	.959080	.95	.658369	5.58	.341631	31
0	9.617727	4.62	9.959023	.97	9.658704	5.58	0.341296	30
1	.618004	4.62	.958965	.95	.659039	5.57	.340961	29
2	.618281	4.62	.958908	.97	.659373	5.58	.340627	28
3	.618558	4.60	.958850	.97	.659708	5.57	.340292	27
4	.618834	4.60	.958792	.97	.660042	5.57	.339958	26
5	9.619110	4.60	9.958734	.95	9.660376	5.57	0.339624	25
6	.619386	4.60	.958677	.97	.660710	5.55	.339290	24
7	.619662	4.60	.958619	.97	.661043	5.57	.338957	23
8	.619938	4.58	.958561	.97	.661377	5.55	.338623	22
9	.620213	4.58	.958503	.97	.661710	5.55	.338290	21
0	9.620488	4.58	9.958445	.97	9.662043	5.55	0.337957	20
1	.620763	4.58	.958387	.97	.662376	5.55	.337624	19
2	.621038	4.58	.958329	.97	.662709	5.55	.337291	18
3	.621313	4.57	.958271	.97	.663042	5.55	.336958	17
4	.621587	4.57	.958213	.98	.663375	5.53	.336625	16
5	9.621861	4.57	9.958154	.97	9.663707	5.53	0.336293	15
6	.622135	4.57	.958096	.97	.664039	5.53	.335961	14
7	.622409	4.55	.958038	.98	.664371	5.53	.335629	13
8	.622682	4.57	.957979	.97	.664703	5.53	.335297	12
9	.622956	4.55	.957921	.97	.665035	5.52	.334965	11
0	9.623229	4.55	9.957863	.98	9.665366	5.53	0.334634	10
1	.623502	4.53	.957804	.97	.665698	5.52	.334302	9
2	.623774	4.55	.957746	.98	.666029	5.52	.333971	8
3	.624047	4.53	.957687	.98	.666360	5.52	.333640	7
4	.624319	4.53	.957628	.97	.666691	5.50	.333309	6
5	9.624591	4.53	9.957570	.98	9.667021	5.52	0.332979	5
6	.624863	4.53	.957511	.98	.667352	5.50	.332648	4
7	.625135	4.52	.957452	.98	.667682	5.52	.332318	3
8	.625406	4.52	.957393	.97	.668013	5.50	.331987	2
9	.625677	4.52	.957335	.98	.668343	5.50	.331657	1
0	9.625948		9.957276		9.668673		0.331327	0
	Cos.	D. 1".	Sin.	D. 1".	Cot.	D. 1".	Tan.	M.

4° 65°

25° 15

M.	Sin.	D. 1″.	Cos.	D. 1″.	Tan.	D. 1″.	Cot.	
0	9.625948	4.52	9.957276	.98	9.668673	5.48	0.331327	60
1	.626219	4.52	.957217	.98	.669002	5.50	.330998	59
2	.626490	4.50	.957158	.98	.669332	5.48	.330668	58
3	.626760	4.50	.957099	.98	.669661	5.50	.330339	57
4	.627030	4.50	.957040	.98	.669991	5.48	.330009	56
5	9.627300	4.50	9.956981	1.00	9.670320	5.48	0.329680	55
6	.627570	4.50	.956921	.98	.670649	5.47	.329351	54
7	.627840	4.48	.956862	.98	.670977	5.48	.329023	53
8	.628109	4.48	.956803	.98	.671306	5.48	.328694	52
9	.628378	4.48	.956744	1.00	.671635	5.47	.328365	51
10	9.628647	4.48	9.956684	.98	9.671963	5.47	0.328037	50
11	.628916	4.48	.956625	.98	.672291	5.47	.327709	49
12	.629185	4.47	.956566	1.00	.672619	5.47	.327381	48
13	.629453	4.47	.956506	.98	.672947	5.45	.327053	47
14	.629721	4.47	.956447	1.00	.673274	5.47	.326726	46
15	9.629989	4.47	9.956387	1.00	9.673602	5.45	0.326398	45
16	.630257	4.45	.956327	.98	.673929	5.47	.326071	44
17	.630524	4.47	.956268	1.00	.674257	5.45	.325743	43
18	.630792	4.45	.956208	1.00	.674584	5.45	.325416	42
19	.631059	4.45	.956148	.98	.674911	5.43	.325089	41
20	9.631326	4.45	9.956089	1.00	9.675237	5.45	0.324763	40
21	.631593	4.43	.956029	1.00	.675564	5.43	.324436	39
22	.631859	4.43	.955969	1.00	.675890	5.45	.324110	38
23	.632125	4.45	.955909	1.00	.676217	5.43	.323783	37
24	.632392	4.43	.955849	1.00	.676543	5.43	.323457	36
25	9.632658	4.42	9.955789	1.00	9.676869	5.42	0.323131	35
26	.632923	4.43	.955729	1.00	.677194	5.43	.322806	34
27	.633189	4.42	.955669	1.00	.677520	5.43	.322480	33
28	.633454	4.42	.955609	1.02	.677846	5.42	.322154	32
29	.633719	4.42	.955548	1.00	.678171	5.42	.321829	31
30	9.633984	4.42	9.955488	1.00	9.678496	5.42	0.321504	30
31	.634249	4.42	.955428	1.00	.678821	5.42	.321179	29
32	.634514	4.40	.955368	1.02	.679146	5.42	.320854	28
33	.634778	4.40	.955307	1.00	.679471	5.40	.320529	27
34	.635042	4.40	.955247	1.02	.679795	5.42	.320205	26
35	9.635306	4.40	9.955186	1.00	9.680120	5.40	0.319880	25
36	.635570	4.40	.955126	1.02	.680444	5.40	.319556	24
37	.635834	4.38	.955065	1.00	.680768	5.40	.319232	23
38	.636097	4.38	.955005	1.02	.681092	5.40	.318908	22
39	.636360	4.38	.954944	1.02	.681416	5.40	.318584	21
40	9.636623	4.38	9.954883	1.00	9.681740	5.38	0.318260	20
41	.636886	4.37	.954823	1.02	.682063	5.40	.317937	19
42	.637148	4.38	.954762	1.02	.682387	5.38	.317613	18
43	.637411	4.37	.954701	1.02	.682710	5.38	.317290	17
44	.637673	4.37	.954640	1.02	.683033	5.38	.316967	16
45	9.637935	4.37	9.954579	1.02	9.683356	5.38	0.316644	15
46	.638197	4.35	.954518	1.02	.683679	5.37	.316321	14
47	.638458	4.37	.954457	1.02	.684001	5.38	.315999	13
48	.638720	4.35	.954396	1.02	.684324	5.37	.315676	12
49	.638981	4.35	.954335	1.02	.684646	5.37	.315354	11
50	9.639242	4.35	9.954274	1.02	9.684968	5.37	0.315032	10
51	.639503	4.35	.954213	1.02	.685290	5.37	.314710	9
52	.639764	4.33	.954152	1.03	.685612	5.37	.314388	8
53	.640024	4.33	.954090	1.02	.685934	5.35	.314066	7
54	.640284	4.33	.954029	1.02	.686255	5.37	.313745	6
55	9.640544	4.33	9.953968	1.03	9.686577	5.35	0.313423	5
56	.640804	4.33	.953906	1.02	.686898	5.35	.313102	4
57	.641064	4.33	.953845	1.03	.687219	5.35	.312781	3
58	.641324	4.32	.953783	1.02	.687540	5.35	.312460	2
59	.641583	4.32	.953722	1.03	.687861	5.35	.312139	1
60	9.641842		9.953660		9.688182		0.311818	0
	Cos.	D. 1″.	Sin.	D. 1″.	Cot.	D. 1″.	Tan.	M

115° 64

26° 153°

M.	Sin.	D. 1″.	Cos.	D. 1″.	Tan.	D. 1″.	Cot.	
0	9.641842	4.32	9.953660	1.02	9.688182	5.33	0.311818	60
1	.642101	4.32	.953599	1.03	.688502	5.35	.311498	59
2	.642360	4.30	.953537	1.03	.688823	5.33	.311177	58
3	.642618	4.32	.953475	1.03	.689143	5.33	.310857	57
4	.642877	4.30	.953413	1.02	.689463	5.33	.310537	56
5	9.643135	4.30	9.953352	1.03	9.689783	5.33	0.310217	55
6	.643393	4.28	.953290	1.03	.690103	5.33	.309897	54
7	.643650	4.30	.953228	1.03	.690423	5.32	.309577	53
8	.643908	4.28	.953166	1.03	.690742	5.33	.309258	52
9	.644165	4.30	.953104	1.03	.691062	5.32	.308938	51
10	9.644423	4.28	9.953042	1.03	9.691381	5.32	0.308619	50
11	.644680	4.27	.952980	1.03	.691700	5.32	.308300	49
12	.644936	4.28	.952918	1.05	.692019	5.32	.307981	48
13	.645193	4.28	.952855	1.03	.692338	5.30	.307662	47
14	.645450	4.27	.952793	1.03	.692656	5.32	.307344	46
15	9.645706	4.27	9.952731	1.03	9.692975	5.30	0.307025	45
16	.645962	4.27	.952669	1.05	.693293	5.32	.306707	44
17	.646218	4.27	.952606	1.03	.693612	5.30	.306388	43
18	.646474	4.25	.952544	1.05	.693930	5.30	.306070	42
19	.646729	4.25	.952481	1.03	.694248	5.30	.305752	41
20	9.646984	4.27	9.952419	1.05	9.694566	5.28	0.305434	40
21	.647240	4.23	.952356	1.03	.694883	5.30	.305117	39
22	.647494	4.25	.952294	1.05	.695201	5.28	.304799	38
23	.647749	4.25	.952231	1.05	.695518	5.30	.304482	37
24	.648004	4.23	.952168	1.03	.695836	5.28	.304164	36
25	9.648258	4.23	9.952106	1.05	9.696153	5.28	0.303847	35
26	.648512	4.23	.952043	1.05	.696470	5.28	.303530	34
27	.648766	4.23	.951980	1.05	.696787	5.27	.303213	33
28	.649020	4.23	.951917	1.05	.697103	5.28	.302897	32
29	.649274	4.22	.951854	1.05	.697420	5.27	.302580	31
30	9.649527	4.23	9.951791	1.05	9.697736	5.28	0.302264	30
31	.649781	4.22	.951728	1.05	.698053	5.27	.301947	29
32	.650034	4.22	.951665	1.05	.698369	5.27	.301631	28
33	.650287	4.20	.951602	1.05	.698685	5.27	.301315	27
34	.650539	4.22	.951539	1.05	.699001	5.25	.300999	26
35	9.650792	4.20	9.951476	1.07	9.699316	5.27	0.300684	25
36	.651044	4.22	.951412	1.05	.699632	5.25	.300368	24
37	.651297	4.20	.951349	1.05	.699947	5.27	.300053	23
38	.651549	4.18	.951286	1.07	.700263	5.25	.299737	22
39	.651800	4.20	.951222	1.05	.700578	5.25	.299422	21
40	9.652052	4.20	9.951159	1.05	9.700893	5.25	0.299107	20
41	.652304	4.18	.951096	1.07	.701208	5.25	.298792	19
42	.652555	4.18	.951032	1.07	.701523	5.23	.298477	18
43	.652806	4.18	.950968	1.05	.701837	5.25	.298163	17
44	.653057	4.18	.950905	1.07	.702152	5.23	.297848	16
45	9.653308	4.17	9.950841	1.05	9.702466	5.25	0.297534	15
46	.653558	4.17	.950778	1.07	.702781	5.23	.297219	14
47	.653808	4.18	.950714	1.07	.703095	5.23	.296905	13
48	.654059	4.17	.950650	1.07	.703409	5.22	.296591	12
49	.654309	4.15	.950586	1.07	.703722	5.23	.296278	11
50	9.654558	4.17	9.950522	1.07	9.704036	5.23	0.295964	10
51	.654808	4.17	.950458	1.07	.704350	5.22	.295650	9
52	.655058	4.15	.950394	1.07	.704663	5.22	.295337	8
53	.655307	4.15	.950330	1.07	.704976	5.23	.295024	7
54	.655556	4.15	.950266	1.07	.705290	5.22	.294710	6
55	9.655805	4.15	9.950202	1.07	9.705603	5.22	0.294397	5
56	.656054	4.13	.950138	1.07	.705916	5.20	.294084	4
57	.656302	4.15	.950074	1.07	.706228	5.22	.293772	3
58	.656551	4.13	.950010	1.08	.706541	5.22	.293459	2
59	.656799	4.13	.949945	1.07	.706854	5.20	.293146	1
60	9.657047		9.949881		9.707166		0.292834	0
	Cos.	D. 1″.	Sin.	D. 1″.	Cot.	D. 1″.	Tan.	M.

6° 63°

27° 152°

M.	Sin.	D. 1″.	Cos.	D. 1″.	Tan.	D. 1″.	Cot.	
0	9.657047	4.13	9.949881	1.08	9.707166	5.20	0.292834	60
1	.657295	4.12	.949816	1.07	.707478	5.20	.292522	59
2	.657542	4.13	.949752	1.07	.707790	5.20	.292210	58
3	.657790	4.12	.949688	1.08	.708102	5.20	.291898	57
4	.658037	4.12	.949623	1.08	.708414	5.20	.291586	56
5	9.658284	4.12	9.949558	1.07	9.708726	5.18	0.291274	55
6	.658531	4.12	.949494	1.08	.709037	5.20	.290963	54
7	.658778	4.12	.949429	1.08	.709349	5.18	.290651	53
8	.659025	4.10	.949364	1.07	.709660	5.18	.290340	52
9	.659271	4.10	.949300	1.08	.709971	5.18	.290029	51
10	9.659517	4.10	9.949235	1.08	9.710282	5.18	0.289718	50
11	.659763	4.10	.949170	1.08	.710593	5.18	.289407	49
12	.660009	4.10	.949105	1.08	.710904	5.18	.289096	48
13	.660255	4.10	.949040	1.08	.711215	5.17	.288785	47
14	.660501	4.08	.948975	1.08	.711525	5.18	.288475	46
15	9.660746	4.08	9.948910	1.08	9.711836	5.17	0.288164	45
16	.660991	4.08	.948845	1.08	.712146	5.17	.287854	44
17	.661236	4.08	.948780	1.08	.712456	5.17	.287544	43
18	.661481	4.08	.948715	1.08	.712766	5.17	.287234	42
19	.661726	4.07	.948650	1.10	.713076	5.17	.286924	41
20	9.661970	4.07	9.948584	1.08	9.713386	5.17	0.286614	40
21	.662214	4.08	.948519	1.08	.713696	5.15	.286304	39
22	.662459	4.07	.948454	1.10	.714005	5.15	.285995	38
23	.662703	4.05	.948388	1.08	.714314	5.17	.285686	37
24	.662946	4.07	.948323	1.10	.714624	5.15	.285376	36
25	9.663190	4.05	9.948257	1.08	9.714933	5.15	0.285067	35
26	.663433	4.07	.948192	1.10	.715242	5.15	.284758	34
27	.663677	4.05	.948126	1.10	.715551	5.15	.284449	33
28	.663920	4.05	.948060	1.08	.715860	5.13	.284140	32
29	.664163	4.05	.947995	1.10	.716168	5.15	.283832	31
30	9.664406	4.03	9.947929	1.10	9.716477	5.13	0.283523	30
31	.664648	4.05	.947863	1.10	.716785	5.13	.283215	29
32	.664891	4.03	.947797	1.10	.717093	5.13	.282907	28
33	.665133	4.03	.947731	1.10	.717401	5.13	.282599	27
34	.665375	4.03	.947665	1.08	.717709	5.13	.282291	26
35	9.665617	4.03	9.947600	1.12	9.718017	5.13	0.281983	25
36	.665859	4.02	.947533	1.10	.718325	5.13	.281675	24
37	.666100	4.03	.947467	1.10	.718633	5.12	.281367	23
38	.666342	4.02	.947401	1.10	.718940	5.13	.281060	22
39	.666583	4.02	.947335	1.10	.719248	5.12	.280752	21
40	9.666824	4.02	9.947269	1.10	9.719555	5.12	0.280445	20
41	.667065	4.00	.947203	1.12	.719862	5.12	.280138	19
42	.667305	4.02	.947136	1.10	.720169	5.12	.279831	18
43	.667546	4.00	.947070	1.10	.720476	5.12	.279524	17
44	.667786	4.02	.947004	1.12	.720783	5.10	.279217	16
45	9.668027	4.00	9.946937	1.10	9.721089	5.12	0.278911	15
46	.668267	3.98	.946871	1.12	.721396	5.10	.278604	14
47	.668506	4.00	.946804	1.10	.721702	5.12	.278298	13
48	.668746	4.00	.946738	1.12	.722009	5.10	.277991	12
49	.668986	3.98	.946671	1.12	.722315	5.10	.277685	11
50	9.669225	3.98	9.946604	1.10	9.722621	5.10	0.277379	10
51	.669464	3.98	.946538	1.12	.722927	5.08	.277073	9
52	.669703	3.98	.946471	1.12	.723232	5.10	.276768	8
53	.669942	3.98	.946404	1.12	.723538	5.10	.276462	7
54	.670181	3.97	.946337	1.12	.723844	5.08	.276156	6
55	9.670419	3.98	9.946270	1.12	9.724149	5.08	0.275851	5
56	.670658	3.97	.946203	1.12	.724454	5.10	.275546	4
57	.670896	3.97	.946136	1.12	.724760	5.08	.275240	3
58	.671134	3.97	.946069	1.12	.725065	5.08	.274935	2
59	.671372	3.95	.946002	1.12	.725370	5.07	.274630	1
60	9.671609		9.945935		9.725674		0.274326	0
	Cos.	D. 1″.	Sin.	D. 1″.	Cot.	D. 1″.	Tan.	M.

117° 62°

28° **151°**

M.	Sin.	D. 1″.	Cos.	D. 1″.	Tan.	D. 1″.	Cot.	
0	9.671609	3.97	9.945935	1.12	9.725674	5.08	0.274326	60
1	.671847	3.95	.945868	1.13	.725979	5.08	.274021	59
2	.672084	3.95	.945800	1.12	.726284	5.07	.273716	58
3	.672321	3.95	.945733	1.12	.726588	5.07	.273412	57
4	.672558	3.95	.945666	1.13	.726892	5.08	.273108	56
5	9.672795	3.95	9.945598	1.12	9.727197	5.07	0.272803	55
6	.673032	3.93	.945531	1.12	.727501	5.07	.272499	54
7	.673268	3.95	.945464	1.13	.727805	5.07	.272195	53
8	.673505	3.93	.945396	1.13	.728109	5.05	.271891	52
9	.673741	3.93	.945328	1.12	.728412	5.07	.271588	51
10	9.673977	3.93	9.945261	1.13	9.728716	5.07	0.271284	50
11	.674213	3.92	.945193	1.13	.729020	5.05	.270980	49
12	.674448	3.93	.945125	1.12	.729323	5.05	.270677	48
13	.674684	3.92	.945058	1.13	.729626	5.05	.270374	47
14	.674919	3.93	.944990	1.13	.729929	5.07	.270071	46
15	9.675155	3.92	9.944922	1.13	9.730233	5.03	0.269767	45
16	.675390	3.90	.944854	1.13	.730535	5.05	.269465	44
17	.675624	3.92	.944786	1.13	.730838	5.05	.269162	43
18	.675859	3.92	.944718	1.13	.731141	5.05	.268859	42
19	.676094	3.90	.944650	1.13	.731444	5.03	.268556	41
20	9.676328	3.90	9.944582	1.13	9.731746	5.03	0.268254	40
21	.676562	3.90	.944514	1.13	.732048	5.05	.267952	39
22	.676796	3.90	.944446	1.15	.732351	5.03	.267649	38
23	.677030	3.90	.944377	1.13	.732653	5.03	.267347	37
24	.677264	3.90	.944309	1.13	.732955	5.03	.267045	36
25	9.677498	3.88	9.944241	1.15	9.733257	5.02	0.266743	35
26	.677731	3.88	.944172	1.13	.733558	5.03	.266442	34
27	.677964	3.88	.944104	1.13	.733860	5.03	.266140	33
28	.678197	3.88	.944036	1.15	.734162	5.02	.265838	32
29	.678430	3.88	.943967	1.13	.734463	5.02	.265537	31
30	9.678663	3.87	9.943899	1.15	9.734764	5.03	0.265236	30
31	.678895	3.88	.943830	1.15	.735066	5.02	.264934	29
32	.679128	3.87	.943761	1.13	.735367	5.02	.264633	28
33	.679360	3.87	.943693	1.15	.735668	5.02	.264332	27
34	.679592	3.87	.943624	1.15	.735969	5.00	.264031	26
35	9.679824	3.87	9.943555	1.15	9.736269	5.02	0.263731	25
36	.680056	3.87	.943486	1.15	.736570	5.00	.263430	24
37	.680288	3.85	.943417	1.15	.736870	5.02	.263130	23
38	.680519	3.85	.943348	1.15	.737171	5.00	.262829	22
39	.680750	3.87	.943279	1.15	.737471	5.00	.262529	21
40	9.680982	3.85	9.943210	1.15	9.737771	5.00	0.262229	20
41	.681213	3.83	.943141	1.15	.738071	5.00	.261929	19
42	.681443	3.85	.943072	1.15	.738371	5.00	.261629	18
43	.681674	3.85	.943003	1.15	.738671	5.00	.261329	17
44	.681905	3.83	.942934	1.17	.738971	5.00	.261029	16
45	9.682135	3.83	9.942864	1.15	9.739271	4.98	0.260729	15
46	.682365	3.83	.942795	1.15	.739570	5.00	.260430	14
47	.682595	3.83	.942726	1.17	.739870	4.98	.260130	13
48	.682825	3.83	.942656	1.15	.740169	4.98	.259831	12
49	.683055	3.82	.942587	1.17	.740468	4.98	.259532	11
50	9.683284	3.83	9.942517	1.15	9.740767	4.98	0.259233	10
51	.683514	3.82	.942448	1.17	.741066	4.98	.258934	9
52	.683743	3.82	.942378	1.17	.741365	4.98	.258635	8
53	.683972	3.82	.942308	1.15	.741664	4.97	.258336	7
54	.684201	3.82	.942239	1.17	.741962	4.98	.258038	6
55	9.684430	3.80	9.942169	1.17	9.742261	4.97	0.257739	5
56	.684658	3.82	.942099	1.17	.742559	4.98	.257441	4
57	.684887	3.80	.942029	1.17	.742858	4.97	.257142	3
58	.685115	3.80	.941959	1.17	.743156	4.97	.256844	2
59	.685343	3.80	.941889	1.17	.743454	4.97	.256546	1
60	9.685571		9.941819		9.743752		0.256248	0
	Cos.	D. 1″.	Sin.	D. 1″.	Cot.	D. 1″.	Tan.	M.

29° 150°

M.	Sin.	D. 1″.	Cos.	D. 1″.	Tan.	D. 1″.	Cot.	
0	9.685571	3.80	9.941819	1.17	9.743752	4.97	0.256248	60
1	.685799	3.80	.941749	1.17	.744050	4.97	.255950	59
2	.686027	3.78	.941679	1.17	.744348	4.95	.255652	58
3	.686254	3.80	.941609	1.17	.744645	4.97	.255355	57
4	.686482	3.78	.941539	1.17	.744943	4.95	.255057	56
5	9.686709	3.78	9.941469	1.18	9.745240	4.97	0.254760	55
6	.686936	3.78	.941398	1.17	.745538	4.95	.254462	54
7	.687163	3.77	.941328	1.17	.745835	4.95	.254165	53
8	.687389	3.78	.941258	1.18	.746132	4.95	.253868	52
9	.687616	3.78	.941187	1.17	.746429	4.95	.253571	51
10	9.687843	3.77	9.941117	1.18	9.746726	4.95	0.253274	50
11	.688069	3.77	.941046	1.18	.747023	4.93	.252977	49
12	.688295	3.77	.940975	1.17	.747319	4.95	.252681	48
13	.688521	3.77	.940905	1.18	.747616	4.95	.252384	47
14	.688747	3.75	.940834	1.18	.747913	4.93	.252087	46
15	9.688972	3.77	9.940763	1.17	9.748209	4.93	0.251791	45
16	.689198	3.75	.940693	1.18	.748505	4.93	.251495	44
17	.689423	3.75	.940622	1.18	.748801	4.93	.251199	43
18	.689648	3.75	.940551	1.18	.749097	4.93	.250903	42
19	.689873	3.75	.940480	1.18	.749393	4.93	.250607	41
20	9.690098	3.75	9.940409	1.18	9.749689	4.93	0.250311	40
21	.690323	3.75	.940338	1.18	.749985	4.93	.250015	39
22	.690548	3.73	.940267	1.18	.750281	4.92	.249719	38
23	.690772	3.73	.940196	1.18	.750576	4.93	.249424	37
24	.690996	3.73	.940125	1.18	.750872	4.92	.249128	36
25	9.691220	3.73	9.940054	1.20	9.751167	4.92	0.248833	35
26	.691444	3.73	.939982	1.18	.751462	4.92	.248538	34
27	.691668	3.73	.939911	1.18	.751757	4.92	.248243	33
28	.691892	3.72	.939840	1.20	.752052	4.92	.247948	32
29	.692115	3.73	.939768	1.18	.752347	4.92	.247653	31
30	9.692339	3.72	9.939697	1.20	9.752642	4.92	0.247358	30
31	.692562	3.72	.939625	1.18	.752937	4.90	.247063	29
32	.692785	3.72	.939554	1.20	.753231	4.92	.246769	28
33	.693008	3.72	.939482	1.20	.753526	4.90	.246474	27
34	.693231	3.70	.939410	1.18	.753820	4.92	.246180	26
35	9.693453	3.72	9.939339	1.20	9.754115	4.90	0.245885	25
36	.693676	3.70	.939267	1.20	.754409	4.90	.245591	24
37	.693898	3.70	.939195	1.20	.754703	4.90	.245297	23
38	.694120	3.70	.939123	1.18	.754997	4.90	.245003	22
39	.694342	3.70	.939052	1.20	.755291	4.90	.244709	21
40	9 694564	3.70	9.938980	1.20	9.755585	4.88	0.244415	20
41	.694786	3.68	.938908	1.20	.755878	4.90	.244122	19
42	.695007	3.70	.938836	1.22	.756172	4.88	.243828	18
43	.695229	3.68	.938763	1.20	.756465	4.90	.243535	17
44	.695450	3.68	.938691	1.20	.756759	4.88	.243241	16
45	9.695671	3.68	9.938619	1.20	9.757052	4.88	0.242948	15
46	.695892	3.68	.938547	1.20	.757345	4.88	.242655	14
47	.696113	3.68	.938475	1.22	.757638	4.88	.242362	13
48	.696334	3.67	.938402	1.20	.757931	4.88	.242069	12
49	.696554	3.68	.938330	1.20	.758224	4.88	.241776	11
50	9.696775	3.67	9.938258	1.22	9.758517	4.88	0.241483	10
51	.696995	3.67	.938185	1.20	.758810	4.87	.241190	9
52	.697215	3.67	.938113	1.22	.759102	4.88	.240898	8
53	.697435	3.65	.938040	1.22	.759395	4.87	.240605	7
54	.697654	3.67	.937967	1.20	.759687	4.87	.240313	6
55	9.697874	3.67	9.937895	1.22	9.759979	4.88	0.240021	5
56	.698094	3.65	.937822	1.22	.760272	4.87	.239728	4
57	.698313	3.65	.937749	1.22	.760564	4.87	.239436	3
58	.698532	3.65	.937676	1.20	.760856	4.87	.239144	2
59	.698751	3.65	.937604	1.22	.761148	4.85	.238852	1
60	9.698970		9.937531		9.761439		0.238561	0
	Cos.	D. 1″.	Sin.	D. 1″.	Cot.	D. 1″.	Tan.	M.

119° 60°

30° 149°

M.	Sin.	D. 1″.	Cos.	D. 1″.	Tan.	D. 1″.	Cot.	
0	9.698970	3.65	9.937531	1.22	9.761439	4.87	0.238561	60
1	.699189	3.63	.937458	1.22	.761731	4.87	.238269	59
2	.699407	3.65	.937385	1.22	.762023	4.85	.237977	58
3	.699626	3.63	.937312	1.23	.762314	4.87	.237686	57
4	.699844	3.63	.937238	1.22	.762606	4.85	.237394	56
5	9.700062	3.63	9.937165	1.22	9.762897	4.85	0.237103	55
6	.700280	3.63	.937092	1.22	.763188	4.85	.236812	54
7	.700498	3.63	.937019	1.22	.763479	4.85	.236521	53
8	.700716	3.62	.936946	1.23	.763770	4.85	.236230	52
9	.700933	3.63	.936872	1.22	.764061	4.85	.235939	51
10	9.701151	3.62	9.936799	1.23	9.764352	4.85	0.235648	50
11	.701368	3.62	.936725	1.22	.764643	4.83	.235357	49
12	.701585	3.62	.936652	1.23	.764933	4.85	.235067	48
13	.701802	3.62	.936578	1.22	.765224	4.83	.234776	47
14	.702019	3.62	.936505	1.23	.765514	4.85	.234486	46
15	9.702236	3.60	9.936431	1.23	9.765805	4.83	0.234195	45
16	.702452	3.62	.936357	1.22	.766095	4.83	.233905	44
17	.702669	3.60	.936284	1.23	.766385	4.83	.233615	43
18	.702885	3.60	.936210	1.23	.766675	4.83	.233325	42
19	.703101	3.60	.936136	1.23	.766965	4.83	.233035	41
20	9.703317	3.60	9.936062	1.23	9.767255	4.83	0.232745	40
21	.703533	3.60	.935988	1.23	.767545	4.82	.232455	39
22	.703749	3.58	.935914	1.23	.767834	4.83	.232166	38
23	.703964	3.58	.935840	1.23	.768124	4.83	.231876	37
24	.704179	3.60	.935766	1.23	.768414	4.82	.231586	36
25	9.704395	3.58	9.935692	1.23	9.768703	4.82	0.231297	35
26	.704610	3.58	.935618	1.25	.768992	4.82	.231008	34
27	.704825	3.58	.935543	1.23	.769281	4.83	.230719	33
28	.705040	3.57	.935469	1.23	.769571	4.82	.230429	32
29	.705254	3.58	.935395	1.25	.769860	4.80	.230140	31
30	9.705469	3.57	9.935320	1.23	9.770148	4.82	0.229852	30
31	.705683	3.58	.935246	1.25	.770437	4.82	.229563	29
32	.705898	3.57	.935171	1.23	.770726	4.82	.229274	28
33	.706112	3.57	.935097	1.25	.771015	4.80	.228985	27
34	.706326	3.55	.935022	1.23	.771303	4.82	.228697	26
35	9.706539	3.57	9.934948	1.25	9.771592	4.80	0.228408	25
36	.706753	3.57	.934873	1.25	.771880	4.80	.228120	24
37	.706967	3.55	.934798	1.25	.772168	4.82	.227832	23
38	.707180	3.55	.934723	1.23	.772457	4.80	.227543	22
39	.707393	3.55	.934649	1.25	.772745	4.80	.227255	21
40	9.707606	3.55	9.934574	1.25	9.773033	4.80	0.226967	20
41	.707819	3.55	.934499	1.25	.773321	4.78	.226679	19
42	.708032	3.55	.934424	1.25	.773608	4.80	.226392	18
43	.708245	3.55	.934349	1.25	.773896	4.80	.226104	17
44	.708458	3.53	.934274	1.25	.774184	4.78	.225816	16
45	9.708670	3.53	9.934199	1.27	9.774471	4.80	0.225529	15
46	.708882	3.53	.934123	1.25	.774759	4.78	.225241	14
47	.709094	3.53	.934048	1.25	.775046	4.78	.224954	13
48	.709306	3.53	.933973	1.25	.775333	4.80	.224667	12
49	.709518	3.53	.933898	1.27	.775621	4.78	.224379	11
50	9.709730	3.52	9.933822	1.25	9.775908	4.78	0.224092	10
51	.709941	3.53	.933747	1.27	.776195	4.78	.223805	9
52	.710153	3.52	.933671	1.25	.776482	4.77	.223518	8
53	.710364	3.52	.933596	1.27	.776768	4.78	.223232	7
54	.710575	3.52	.933520	1.25	.777055	4.78	.222945	6
55	9.710786	3.52	9.933445	1.27	9.777342	4.77	0.222658	5
56	.710997	3.52	.933369	1.27	.777628	4.78	.222372	4
57	.711208	3.52	.933293	1.27	.777915	4.77	.222085	3
58	.711419	3.50	.933217	1.27	.778201	4.78	.221799	2
59	.711629	3.50	.933141	1.25	.778488	4.77	.221512	1
60	9.711839		9.933066		9.778774		0.221226	0
	Cos.	D. 1″.	Sin.	D. 1″.	Cot.	D. 1″.	Tan.	M.

120° 59°

31° | 14

M.	Sin.	D. 1″.	Cos.	D. 1″.	Tan.	D. 1″.	Cot.	
0	9.711839	3.52	9.933066	1.27	9.778774	4.77	0.221226	60
1	.712050	3.50	.932990	1.27	.779060	4.77	.220940	59
2	.712260	3.48	.932914	1.27	.779346	4.77	.220654	58
3	.712469	3.50	.932838	1.27	.779632	4.77	.220368	57
4	.712679	3.50	.932762	1.28	.779918	4.75	.220082	56
5	9.712889	3.48	9.932685	1.27	9.780203	4.77	0.219797	55
6	.713098	3.50	.932609	1.27	.780489	4.77	.219511	54
7	.713308	3.48	.932533	1.27	.780775	4.75	.219225	53
8	.713517	3.48	.932457	1.28	.781060	4.77	.218940	52
9	.713726	3.48	.932380	1.27	.781346	4.75	.218654	51
10	9.713935	3.48	9.932304	1.27	9.781631	4.75	0.218369	50
11	.714144	3.47	.932228	1.28	.781916	4.75	.218084	49
12	.714352	3.48	.932151	1.27	.782201	4.75	.217799	48
13	.714561	3.47	.932075	1.28	.782486	4.75	.217514	47
14	.714769	3.48	.931998	1.28	.782771	4.75	.217229	46
15	9.714978	3.47	9.931921	1.27	9.783056	4.75	0.216944	45
16	.715186	3.47	.931845	1.28	.783341	4.75	.216659	44
17	.715394	3.47	.931768	1.28	.783626	4.73	.216374	43
18	.715602	3.45	.931691	1.28	.783910	4.75	.216090	42
19	.715809	3.47	.931614	1.28	.784195	4.73	.215805	41
20	9.716017	3.45	9.931537	1.28	9.784479	4.75	0.215521	40
21	.716224	3.47	.931460	1.28	.784764	4.73	.215236	39
22	.716432	3.45	.931383	1.28	.785048	4.73	.214952	38
23	.716639	3.45	.931306	1.28	.785332	4.73	.214668	37
24	.716846	3.45	.931229	1.28	.785616	4.73	.214384	36
25	9.717053	3.43	9.931152	1.28	9.785900	4.73	0.214100	35
26	.717259	3.45	.931075	1.28	.786184	4.73	.213816	34
27	.717466	3.45	.930998	1.28	.786468	4.73	.213532	33
28	.717673	3.43	.930921	1.30	.786752	4.73	.213248	32
29	.717879	3.43	.930843	1.28	.787036	4.72	.212964	31
30	9.718085	3.43	9.930766	1.30	9.787319	4.73	0.212681	30
31	.718291	3.43	.930688	1.28	.787603	4.72	.212397	29
32	.718497	3.43	.930611	1.30	.787886	4.73	.212114	28
33	.718703	3.43	.930533	1.28	.788170	4.72	.211830	27
34	.718909	3.42	.930456	1.30	.788453	4.72	.211547	26
35	9.719114	3.43	9.930378	1.30	9.788736	4.72	0.211264	25
36	.719320	3.42	.930300	1.28	.789019	4.72	.210981	24
37	.719525	3.42	.930223	1.30	.789302	4.72	.210698	23
38	.719730	3.42	.930145	1.30	.789585	4.72	.210415	22
39	.719935	3.42	.930067	1.30	.789868	4.72	.210132	21
40	9.720140	3.42	9.929989	1.30	9.790151	4.72	0.209849	20
41	.720345	3.40	.929911	1.30	.790434	4.70	.209566	19
42	.720549	3.42	.929833	1.30	.790716	4.72	.209284	18
43	.720754	3.40	.929755	1.30	.790999	4.70	.209001	17
44	.720958	3.40	.929677	1.30	.791281	4.70	.208719	16
45	9.721162	3.40	9.929599	1.30	9.791563	4.72	0.208437	15
46	.721366	3.40	.929521	1.32	.791846	4.70	.208154	14
47	.721570	3.40	.929442	1.30	.792128	4.70	.207872	13
48	.721774	3.40	.929364	1.30	.792410	4.70	.207590	12
49	.721978	3.38	.929286	1.32	.792692	4.70	.207308	11
50	9.722181	3.40	9.929207	1.30	9.792974	4.70	0.207026	10
51	.722385	3.38	.929129	1.32	.793256	4.70	.206744	9
52	.722588	3.38	.929050	1.30	.793538	4.68	.206462	8
53	.722791	3.38	.928972	1.32	.793819	4.70	.206181	7
54	.722994	3.38	.928893	1.30	.794101	4.70	.205899	6
55	9.723197	3.38	9.928815	1.32	9.794383	4.68	0.205617	5
56	.723400	3.38	.928736	1.32	.794664	4.70	.205336	4
57	.723603	3.37	.928657	1.32	.794946	4.68	.205054	3
58	.723805	3.37	.928578	1.32	.795227	4.68	.204773	2
59	.724007	3.38	.928499	1.32	.795508	4.68	.204492	1
60	9.724210		9.928420		9.795789		0.204211	0
	Cos.	D. 1″.	Sin.	D. 1″.	Cot.	D. 1″.	Tan.	M.

32° 147°

M.	Sin.	D. 1″.	Cos.	D. 1″.	Tan.	D. 1″.	Cot.	
0	9.724210	3.37	9.928420	1.30	9.795789	4.68	0.204211	60
1	.724412	3.37	.928342	1.32	.796070	4.68	.203930	59
2	.724614	3.37	.928263	1.33	.796351	4.68	.203649	58
3	.724816	3.35	.928183	1.32	.796632	4.68	.203368	57
4	.725017	3.37	.928104	1.32	.796913	4.68	.203087	56
5	9.725219	3.35	9.928025	1.32	9.797194	4.67	0.202806	55
6	.725420	3.37	.927946	1.32	.797474	4.68	.202526	54
7	.725622	3.35	.927867	1.33	.797755	4.68	.202245	53
8	.725823	3.35	.927787	1.32	.798036	4.67	.201964	52
9	.726024	3.35	.927708	1.32	.798316	4.67	.201684	51
10	9.726225	3.35	9.927629	1.33	9.798596	4.68	0.201404	50
11	.726426	3.33	.927549	1.32	.798877	4.67	.201123	49
12	.726626	3.35	.927470	1.33	.799157	4.67	.200843	48
13	.726827	3.33	.927390	1.33	.799437	4.67	.200563	47
14	.727027	3.35	.927310	1.32	.799717	4.67	.200283	46
15	9.727228	3.33	9.927231	1.33	9.799997	4.67	0.200003	45
16	.727428	3.33	.927151	1.33	.800277	4.67	.199723	44
17	.727628	3.33	.927071	1.33	.800557	4.65	.199443	43
18	.727828	3.32	.926991	1.33	.800836	4.67	.199164	42
19	.728027	3.33	.926911	1.33	.801116	4.67	.198884	41
20	9.728227	3.33	9.926831	1.33	9.801396	4.65	0.198604	40
21	.728427	3.32	.926751	1.33	.801675	4.67	.198325	39
22	.728626	3.32	.926671	1.33	.801955	4.65	.198045	38
23	.728825	3.32	.926591	1.33	.802234	4.65	.197766	37
24	.729024	3.32	.926511	1.33	.802513	4.65	.197487	36
25	9.729223	3.32	9.926431	1.33	9.802792	4.67	0.197208	35
26	.729422	3.32	.926351	1.35	.803072	4.65	.196928	34
27	.729621	3.32	.926270	1.33	.803351	4.65	.196649	33
28	.729820	3.30	.926190	1.33	.803630	4.65	.196370	32
29	.730018	3.32	.926110	1.35	.803909	4.63	.196091	31
30	9.730217	3.30	9.926029	1.33	9.804187	4.65	0.195813	30
31	.730415	3.30	.925949	1.35	.804466	4.65	.195534	29
32	.730613	3.30	.925868	1.33	.804745	4.63	.195255	28
33	.730811	3.30	.925788	1.35	.805023	4.65	.194977	27
34	.731009	3.28	.925707	1.35	.805302	4.63	.194698	26
35	9.731206	3.30	9.925626	1.35	9.805580	4.65	0.194420	25
36	.731404	3.30	.925545	1.33	.805859	4.63	.194141	24
37	.731602	3.28	.925465	1.35	.806137	4.63	.193863	23
38	.731799	3.28	.925384	1.35	.806415	4.63	.193585	22
39	.731996	3.28	.925303	1.35	.806693	4.63	.193307	21
40	9.732193	3.28	9.925222	1.35	9.806971	4.63	0.193029	20
41	.732390	3.28	.925141	1.35	.807249	4.63	.192751	19
42	.732587	3.28	.925060	1.35	.807527	4.63	.192473	18
43	.732784	3.27	.924979	1.37	.807805	4.63	.192195	17
44	.732980	3.28	.924897	1.35	.808083	4.63	.191917	16
45	9.733177	3.27	9.924816	1.35	9.808361	4.62	0.191639	15
46	.733373	3.27	.924735	1.35	.808638	4.63	.191362	14
47	.733569	3.27	.924654	1.37	.808916	4.62	.191084	13
48	.733765	3.27	.924572	1.35	.809193	4.63	.190807	12
49	.733961	3.27	.924491	1.37	.809471	4.62	.190529	11
50	9.734157	3.27	9.924409	1.35	9.809748	4.62	0.190252	10
51	.734353	3.27	.924328	1.37	.810025	4.62	.189975	9
52	.734549	3.25	.924246	1.37	.810302	4.63	.189698	8
53	.734744	3.25	.924164	1.35	.810580	4.62	.189420	7
54	.734939	3.27	.924083	1.37	.810857	4.62	.189143	6
55	9.735135	3.25	9.924001	1.37	9.811134	4.60	0.188866	5
56	.735330	3.25	.923919	1.37	.811410	4.62	.188590	4
57	.735525	3.23	.923837	1.37	.811687	4.62	.188313	3
58	.735719	3.25	.923755	1.37	.811964	4.62	.188036	2
59	.735914	3.25	.923673	1.37	.812241	4.60	.187759	1
60	9.736109		9.923591		9.812517		0.187483	0
	Cos.	D. 1″.	Sin.	D. 1″.	Cot.	D. 1″.	Tan.	M.

33° | 146°

M.	Sin.	D. 1″.	Cos.	D. 1″.	Tan.	D. 1″.	Cot.	
0	9.736109	3.23	9.923591	1.37	9.812517	4.62	0.187483	60
1	.736303	3.25	.923509	1.37	.812794	4.60	.187206	59
2	.736498	3.23	.923427	1.37	.813070	4.62	.186930	58
3	.736692	3.23	.923345	1.37	.813347	4.60	.186653	57
4	.736886	3.23	.923263	1.37	.813623	4.60	.186377	56
5	9.737080	3.23	9.923181	1.38	9.813899	4.62	0.186101	55
6	.737274	3.22	.923098	1.37	.814176	4.60	.185824	54
7	.737467	3.23	.923016	1.38	.814452	4.60	.185548	53
8	.737661	3.23	.922933	1.37	.814728	4.60	.185272	52
9	.737855	3.22	.922851	1.38	.815004	4.60	.184996	51
10	9.738048	3.22	9.922768	1.37	9.815280	4.58	0.184720	50
11	.738241	3.22	.922686	1.38	.815555	4.60	.184445	49
12	.738434	3.22	.922603	1.38	.815831	4.60	.184169	48
13	.738627	3.22	.922520	1.37	.816107	4.58	.183893	47
14	.738820	3.22	.922438	1.38	.816382	4.60	.183618	46
15	9.739013	3.22	9.922355	1.38	9.816658	4.58	0.183342	45
16	.739206	3.20	.922272	1.38	.816933	4.60	.183067	44
17	.739398	3.20	.922189	1.38	.817209	4.58	.182791	43
18	.739590	3.22	.922106	1.38	.817484	4.58	.182516	42
19	.739783	3.20	.922023	1.38	.817759	4.60	.182241	41
20	9.739975	3.20	9.921940	1.38	9.818035	4.58	0.181965	40
21	.740167	3.20	.921857	1.38	.818310	4.58	.181690	39
22	.740359	3.18	.921774	1.38	.818585	4.58	.181415	38
23	.740550	3.20	.921691	1.40	.818860	4.58	.181140	37
24	.740742	3.20	.921607	1.38	.819135	4.58	.180865	36
25	9.740934	3.18	9.921524	1.38	9.819410	4.57	0.180590	35
26	.741125	3.18	.921441	1.40	.819684	4.58	.180316	34
27	.741316	3.20	.921357	1.38	.819959	4.58	.180041	33
28	.741508	3.18	.921274	1.40	.820234	4.57	.179766	32
29	.741699	3.17	.921190	1.38	.820508	4.58	.179492	31
30	9.741889	3.18	9.921107	1.40	9.820783	4.57	0.179217	30
31	.742080	3.18	.921023	1.40	.821057	4.58	.178943	29
32	.742271	3.18	.920939	1.38	.821332	4.57	.178668	28
33	.742462	3.17	.920856	1.40	.821606	4.57	.178394	27
34	.742652	3.17	.920772	1.40	.821880	4.57	.178120	26
35	9.742842	3.18	9.920688	1.40	9.822154	4.58	0.177846	25
36	.743033	3.17	.920604	1.40	.822429	4.57	.177571	24
37	.743223	3.17	.920520	1.40	.822703	4.57	.177297	23
38	.743413	3.15	.920436	1.40	.822977	4.57	.177023	22
39	.743602	3.17	.920352	1.40	.823251	4.55	.176749	21
40	9.743792	3.17	9.920268	1.40	9.823524	4.57	0.176476	20
41	.743982	3.15	.920184	1.42	.823798	4.57	.176202	19
42	.744171	3.17	.920099	1.40	.824072	4.55	.175928	18
43	.744361	3.15	.920015	1.40	.824345	4.57	.175655	17
44	.744550	3.15	.919931	1.42	.824619	4.57	.175381	16
45	9.744739	3.15	9.919846	1.40	9.824893	4.55	0.175107	15
46	.744928	3.15	.919762	1.42	.825166	4.55	.174834	14
47	.745117	3.15	.919677	1.40	.825439	4.57	.174561	13
48	.745306	3.13	.919593	1.42	.825713	4.55	.174287	12
49	.745494	3.15	.919508	1.40	.825986	4.55	.174014	11
50	9.745683	3.13	9.919424	1.42	9.826259	4.55	0.173741	10
51	.745871	3.15	.919339	1.42	.826532	4.55	.173468	9
52	.746060	3.13	.919254	1.42	.826805	4.55	.173195	8
53	.746248	3.13	.919169	1.40	.827078	4.55	.172922	7
54	.746436	3.13	.919085	1.42	.827351	4.55	.172649	6
55	9.746624	3.13	9.919000	1.42	9.827624	4.55	0.172376	5
56	.746812	3.12	.918915	1.42	.827897	4.55	.172103	4
57	.746999	3.13	.918830	1.42	.828170	4.53	.171830	3
58	.747187	3.12	.918745	1.43	.828442	4.55	.171558	2
59	.747374	3.13	.918659	1.42	.828715	4.53	.171285	1
60	9.747562		9.918574		9.828987		0.171013	0
	Cos.	D. 1″.	Sin.	D. 1″.	Cot.	D. 1″.	Tan.	M.

123° | 56°

34° | 145°

M.	Sin.	D. 1″.	Cos.	D. 1″.	Tan.	D. 1″.	Cot.	
0	9.747562	3.12	9.918574	1.42	9.828987	4.55	0.171013	60
1	.747749	3.12	.918489	1.42	.829260	4.53	.170740	59
2	.747936	3.12	.918404	1.43	.829532	4.55	.170468	58
3	.748123	3.12	.918318	1.42	.829805	4.53	.170195	57
4	.748310	3.12	.918233	1.43	.830077	4.53	.169923	56
5	9.748497	3.10	9.918147	1.42	9.830349	4.53	0.169651	55
6	.748683	3.12	.918062	1.43	.830621	4.53	.169379	54
7	.748870	3.10	.917976	1.42	.830893	4.53	.169107	53
8	.749056	3.12	.917891	1.43	.831165	4.53	.168835	52
9	.749243	3.10	.917805	1.43	.831437	4.53	.168563	51
10	9.749429	3.10	9.917719	1.42	9.831709	4.53	0.168291	50
11	.749615	3.10	.917634	1.43	.831981	4.53	.168019	49
12	.749801	3.10	.917548	1.43	.832253	4.53	.167747	48
13	.749987	3.08	.917462	1.43	.832525	4.52	.167475	47
14	.750172	3.10	.917376	1.43	.832796	4.53	.167204	46
15	9.750358	3.08	9.917290	1.43	9.833068	4.52	0.166932	45
16	.750543	3.10	.917204	1.43	.833339	4.53	.166661	44
17	.750729	3.08	.917118	1.43	.833611	4.52	.166389	43
18	.750914	3.08	.917032	1.43	.833882	4.53	.166118	42
19	.751099	3.08	.916946	1.45	.834154	4.52	.165846	41
20	9.751284	3.08	9.916859	1.43	9.834425	4.52	0.165575	40
21	.751469	3.08	.916773	1.43	.834696	4.52	.165304	39
22	.751654	3.08	.916687	1.45	.834967	4.52	.165033	38
23	.751839	3.07	.916600	1.43	.835238	4.52	.164762	37
24	.752023	3.08	.916514	1.45	.835509	4.52	.164491	36
25	9.752208	3.07	9.916427	1.43	9.835780	4.52	0.164220	35
26	.752392	3.07	.916341	1.45	.836051	4.52	.163949	34
27	.752576	3.07	.916254	1.45	.836322	4.52	.163678	33
28	.752760	3.07	.916167	1.43	.836593	4.52	.163407	32
29	.752944	3.07	.916081	1.45	.836864	4.50	.163136	31
30	9.753128	3.07	9.915994	1.45	9.837134	4.52	0.162866	30
31	.753312	3.05	.915907	1.45	.837405	4.50	.162595	29
32	.753495	3.07	.915820	1.45	.837675	4.52	.162325	28
33	.753679	3.05	.915733	1.45	.837946	4.50	.162054	27
34	.753862	3.07	.915646	1.45	.838216	4.52	.161784	26
35	9.754046	3.05	9.915559	1.45	9.838487	4.50	0.161513	25
36	.754229	3.05	.915472	1.45	.838757	4.50	.161243	24
37	.754412	3.05	.915385	1.47	.839027	4.50	.160973	23
38	.754595	3.05	.915297	1.45	.839297	4.52	.160703	22
39	.754778	3.03	.915210	1.45	.839568	4.50	.160432	21
40	9.754960	3.05	9.915123	1.47	9.839838	4.50	0.160162	20
41	.755143	3.05	.915035	1.45	.840108	4.50	.159892	19
42	.755326	3.03	.914948	1.47	.840378	4.50	.159622	18
43	.755508	3.03	.914860	1.45	.840648	4.48	.159352	17
44	.755690	3.03	.914773	1.47	.840917	4.50	.159083	16
45	9.755872	3.03	9.914685	1.45	9.841187	4.50	0.158813	15
46	.756054	3.03	.914598	1.47	.841457	4.50	.158543	14
47	.756236	3.03	.914510	1.47	.841727	4.48	.158273	13
48	.756418	3.03	.914422	1.47	.841996	4.50	.158004	12
49	.756600	3.03	.914334	1.47	.842266	4.48	.157734	11
50	9.756782	3.02	9.914246	1.47	9.842535	4.50	0.157465	10
51	.756963	3.02	.914158	1.47	.842805	4.48	.157195	9
52	.757144	3.03	.914070	1.47	.843074	4.48	.156926	8
53	.757326	3.02	.913982	1.47	.843343	4.48	.156657	7
54	.757507	3.02	.913894	1.47	.843612	4.50	.156388	6
55	9.757688	3.02	9.913806	1.47	9.843882	4.48	0.156118	5
56	.757869	3.02	.913718	1.47	.844151	4.48	.155849	4
57	.758050	3.00	.913630	1.48	.844420	4.48	.155580	3
58	.758230	3.02	.913541	1.47	.844689	4.48	.155311	2
59	.758411	3.00	.913453	1.47	.844958	4.48	.155042	1
60	9.758591		9.913365		9.845227		0.154773	0
	Cos.	D. 1″.	Sin.	D. 1″.	Cot.	D. 1″.	Tan.	M.

124° | 55°

35° 144°

M.	Sin.	D. 1″.	Cos.	D. 1″.	Tan.	D. 1″.	Cot.	
0	9.758591	3.02	9.913365	1.48	9.845227	4.48	0.154773	60
1	.758772	3.00	.913276	1.48	.845496	4.47	.154504	59
2	.758952	3.00	.913187	1.47	.845764	4.48	.154236	58
3	.759132	3.00	.913099	1.48	.846033	4.48	.153967	57
4	.759312	3.00	.913010	1.47	.846302	4.47	.153698	56
5	9.759492	3.00	9.912922	1.48	9.846570	4.48	0.153430	55
6	.759672	3.00	.912833	1.48	.846839	4.48	.153161	54
7	.759852	2.98	.912744	1.48	.847108	4.47	.152892	53
8	.760031	3.00	.912655	1.48	.847376	4.47	.152624	52
9	.760211	2.98	.912566	1.48	.847644	4.48	.152356	51
10	9.760390	2.98	9.912477	1.48	9.847913	4.47	0.152087	50
11	.760569	2.98	.912388	1.48	.848181	4.47	.151819	49
12	.760748	2.98	.912299	1.48	.848449	4.47	.151551	48
13	.760927	2.98	.912210	1.48	.848717	4.48	.151283	47
14	.761106	2.98	.912121	1.50	.848986	4.47	.151014	46
15	9.761285	2.98	9.912031	1.48	9.849254	4.47	0.150746	45
16	.761464	2.97	.911942	1.48	.849522	4.47	.150478	44
17	.761642	2.98	.911853	1.50	.849790	4.45	.150210	43
18	.761821	2.97	.911763	1.48	.850057	4.47	.149943	42
19	.761999	2.97	.911674	1.50	.850325	4.47	.149675	41
20	9.762177	2.98	9.911584	1.48	9.850593	4.47	0.149407	40
21	.762356	2.97	.911495	1.50	.850861	4.47	.149139	39
22	.762534	2.97	.911405	1.50	.851129	4.45	.148871	38
23	.762712	2.95	.911315	1.48	.851396	4.47	.148604	37
24	.762889	2.97	.911226	1.50	.851664	4.45	.148336	36
25	9.763067	2.97	9.911136	1.50	9.851931	4.47	0.148069	35
26	.763245	2.95	.911046	1.50	.852199	4.45	.147801	34
27	.763422	2.97	.910956	1.50	.852466	4.45	.147534	33
28	.763600	2.95	.910866	1.50	.852733	4.47	.147267	32
29	.763777	2.95	.910776	1.50	.853001	4.45	.146999	31
30	9.763954	2.95	9.910686	1.50	9.853268	4.45	0.146732	30
31	.764131	2.95	.910596	1.50	.853535	4.45	.146465	29
32	.764308	2.95	.910506	1.52	.853802	4.45	.146198	28
33	.764485	2.95	.910415	1.50	.854069	4.45	.145931	27
34	.764662	2.93	.910325	1.50	.854336	4.45	.145664	26
35	9.764838	2.95	9.910235	1.52	9.854603	4.45	0.145397	25
36	.765015	2.93	.910144	1.50	.854870	4.45	.145130	24
37	.765191	2.93	.910054	1.52	.855137	4.45	.144863	23
38	.765367	2.95	.909963	1.50	.855404	4.45	.144596	22
39	.765544	2.93	.909873	1.52	.855671	4.45	.144329	21
40	9.765720	2.93	9.909782	1.52	9.855938	4.43	0.144062	20
41	.765896	2.93	.909691	1.50	.856204	4.45	.143796	19
42	.766072	2.92	.909601	1.52	.856471	4.43	.143529	18
43	.766247	2.93	.909510	1.52	.856737	4.45	.143263	17
44	.766423	2.92	.909419	1.52	.857004	4.43	.142996	16
45	9.766598	2.93	9.909328	1.52	9.857270	4.45	0.142730	15
46	.766774	2.92	.909237	1.52	.857537	4.43	.142463	14
47	.766949	2.92	.909146	1.52	.857803	4.43	.142197	13
48	.767124	2.93	.909055	1.52	.858069	4.45	.141931	12
49	.767300	2.92	.908964	1.52	.858336	4.43	.141664	11
50	9.767475	2.90	9.908873	1.53	9.858602	4.43	0.141398	10
51	.767649	2.92	.908781	1.52	.858868	4.43	.141132	9
52	.767824	2.92	.908690	1.52	.859134	4.43	.140866	8
53	.767999	2.90	.908599	1.53	.859400	4.43	.140600	7
54	.768173	2.92	.908507	1.52	.859666	4.43	.140334	6
55	9.768348	2.90	9.908416	1.53	9.859932	4.43	0.140068	5
56	.768522	2.92	.908324	1.52	.860198	4.43	.139802	4
57	.768697	2.90	.908233	1.53	.860464	4.43	.139536	3
58	.768871	2.90	.908141	1.53	.860730	4.42	.139270	2
59	.769045	2.90	.908049	1.52	.860995	4.43	.139005	1
60	9.769219		9.907958		9.861261		0.138739	0
	Cos.	D. 1″.	Sin.	D. 1″.	Cot.	D. 1″.	Tan.	M.

36° 143°

M.	Sin.	D. 1″.	Cos.	D. 1″.	Tan.	D. 1″.	Cot.	
0	9.769219	2.90	9.907958	1.53	9.861261	4.43	0.138739	60
1	.769393	2.88	.907866	1.53	.861527	4.42	.138473	59
2	.769566	2.90	.907774	1.53	.861792	4.43	.138208	58
3	.769740	2.88	.907682	1.53	.862058	4.42	.137942	57
4	.769913	2.90	.907590	1.53	.862323	4.43	.137677	56
5	9.770087	2.88	9.907498	1.53	9.862589	4.42	0.137411	55
6	.770260	2.88	.907406	1.53	.862854	4.42	.137146	54
7	.770433	2.88	.907314	1.53	.863119	4.43	.136881	53
8	.770606	2.88	.907222	1.55	.863385	4.42	.136615	52
9	.770779	2.88	.907129	1.53	.863650	4.42	.136350	51
10	9.770952	2.88	9.907037	1.53	9.863915	4.42	0.136085	50
11	.771125	2.88	.906945	1.55	.864180	4.42	.135820	49
12	.771298	2.87	.906852	1.53	.864445	4.42	.135555	48
13	.771470	2.88	.906760	1.55	.864710	4.42	.135290	47
14	.771643	2.87	.906667	1.53	.864975	4.42	.135025	46
15	9.771815	2.87	9.906575	1.55	9.865240	4.42	0.134760	45
16	.771987	2.87	.906482	1.55	.865505	4.42	.134495	44
17	.772159	2.87	.906389	1.55	.865770	4.42	.134230	43
18	.772331	2.87	.906296	1.53	.866035	4.42	.133965	42
19	.772503	2.87	.906204	1.55	.866300	4.40	.133700	41
20	9.772675	2.87	9.906111	1.55	9.866564	4.42	0.133436	40
21	.772847	2.85	.906018	1.55	.866829	4.42	.133171	39
22	.773018	2.87	.905925	1.55	.867094	4.40	.132906	38
23	.773190	2.85	.905832	1.55	.867358	4.42	.132642	37
24	.773361	2.87	.905739	1.57	.867623	4.40	.132377	36
25	9.773533	2.85	9.905645	1.55	9.867887	4.42	0.132113	35
26	.773704	2.85	.905552	1.55	.868152	4.40	.131848	34
27	.773875	2.85	.905459	1.55	.868416	4.40	.131584	33
28	.774046	2.85	.905366	1.57	.868680	4.42	.131320	32
29	.774217	2.85	.905272	1.55	.868945	4.40	.131055	31
30	9.774388	2.83	9.905179	1.57	9.869209	4.40	0.130791	30
31	.774558	2.85	.905085	1.55	.869473	4.40	.130527	29
32	.774729	2.83	.904992	1.57	.869737	4.40	.130263	28
33	.774899	2.85	.904898	1.57	.870001	4.40	.129999	27
34	.775070	2.83	.904804	1.55	.870265	4.40	.129735	26
35	9.775240	2.83	9.904711	1.57	9.870529	4.40	0.129471	25
36	.775410	2.83	.904617	1.57	.870793	4.40	.129207	24
37	.775580	2.83	.904523	1.57	.871057	4.40	.128943	23
38	.775750	2.83	.904429	1.57	.871321	4.40	.128679	22
39	.775920	2.83	.904335	1.57	.871585	4.40	.128415	21
40	9.776090	2.82	9.904241	1.57	9.871849	4.38	0.128151	20
41	.776259	2.83	.904147	1.57	.872112	4.40	.127888	19
42	.776429	2.82	.904053	1.57	.872376	4.40	.127624	18
43	.776598	2.83	.903959	1.58	.872640	4.38	.127360	17
44	.776768	2.82	.903864	1.57	.872903	4.40	.127097	16
45	9.776937	2.82	9.903770	1.57	9.873167	4.38	0.126833	15
46	.777106	2.82	.903676	1.58	.873430	4.40	.126570	14
47	.777275	2.82	.903581	1.57	.873694	4.38	.126306	13
48	.777444	2.82	.903487	1.58	.873957	4.38	.126043	12
49	.777613	2.80	.903392	1.57	.874220	4.40	.125780	11
50	9.777781	2.82	9.903298	1.58	9.874484	4.38	0.125516	10
51	.777950	2.82	.903203	1.58	.874747	4.38	.125253	9
52	.778119	2.80	.903108	1.57	.875010	4.38	.124990	8
53	.778287	2.80	.903014	1.58	.875273	4.40	.124727	7
54	.778455	2.82	.902919	1.58	.875537	4.38	.124463	6
55	9.778624	2.80	9.902824	1.58	9.875800	4.38	0.124200	5
56	.778792	2.80	.902729	1.58	.876063	4.38	.123937	4
57	.778960	2.80	.902634	1.58	.876326	4.38	.123674	3
58	.779128	2.78	.902539	1.58	.876589	4.38	.123411	2
59	.779295	2.80	.902444	1.58	.876852	4.37	.123148	1
60	9.779463		9.902349		9.877114		0.122886	0
	Cos.	D. 1″.	Sin.	D. 1″.	Cot.	D. 1″.	Tan.	M.

126° 53°

37° 142°

M.	Sin.	D. 1″.	Cos.	D. 1″.	Tan.	D. 1″.	Cot.	
0	9.779463	2.80	9.902349	1.60	9.877114	4.38	0.122886	60
1	.779631	2.78	.902253	1.58	.877377	4.38	.122623	59
2	.779798	2.80	.902158	1.58	.877640	4.38	.122360	58
3	.779966	2.78	.902063	1.60	.877903	4.37	.122097	57
4	.780133	2.78	.901967	1.58	.878165	4.38	.121835	56
5	9.780300	2.78	9.901872	1.60	9.878428	4.38	0.121572	55
6	.780467	2.78	.901776	1.58	.878691	4.37	.121309	54
7	.780634	2.78	.901681	1.60	.878953	4.38	.121047	53
8	.780801	2.78	.901585	1.58	.879216	4.37	.120784	52
9	.780968	2.77	.901490	1.60	.879478	4.38	.120522	51
10	9.781134	2.78	9.901394	1.60	9.879741	4.37	0.120259	50
11	.781301	2.78	.901298	1.60	.880003	4.37	.119997	49
12	.781468	2.77	.901202	1.60	.880265	4.38	.119735	48
13	.781634	2.77	.901106	1.60	.880528	4.37	.119472	47
14	.781800	2.77	.901010	1.60	.880790	4.37	.119210	46
15	9.781966	2.77	9.900914	1.60	9.881052	4.37	0.118948	45
16	.782132	2.77	.900818	1.60	.881314	4.38	.118686	44
17	.782298	2.77	.900722	1.60	.881577	4.37	.118423	43
18	.782464	2.77	.900626	1.62	.881839	4.37	.118161	42
19	.782630	2.77	.900529	1.60	.882101	4.37	.117899	41
20	9.782796	2.75	9.900433	1.60	9.882363	4.37	0.117637	40
21	.782961	2.77	.900337	1.62	.882625	4.37	.117375	39
22	.783127	2.75	.900240	1.60	.882887	4.35	.117113	38
23	.783292	2.77	.900144	1.62	.883148	4.37	.116852	37
24	.783458	2.75	.900047	1.60	.883410	4.37	.116590	36
25	9.783623	2.75	9.899951	1.62	9.883672	4.37	0.116328	35
26	.783788	2.75	.899854	1.62	.883934	4.37	.116066	34
27	.783953	2.75	.899757	1.62	.884196	4.35	.115804	33
28	.784118	2.73	.899660	1.60	.884457	4.37	.115543	32
29	.784282	2.75	.899564	1.62	.884719	4.35	.115281	31
30	9.784447	2.75	9.899467	1.62	9.884980	4.37	0.115020	30
31	.784612	2.73	.899370	1.62	.885242	4.37	.114758	29
32	.784776	2.75	.899273	1.62	.885504	4.35	.114496	28
33	.784941	2.73	.899176	1.63	.885765	4.35	.114235	27
34	.785105	2.73	.899078	1.62	.886026	4.37	.113974	26
35	9.785269	2.73	9.898981	1.62	9.886288	4.35	0.113712	25
36	.785433	2.73	.898884	1.62	.886549	4.37	.113451	24
37	.785597	2.73	.898787	1.63	.886811	4.35	.113189	23
38	.785761	2.73	.898689	1.62	.887072	4.35	.112928	22
39	.785925	2.73	.898592	1.63	.887333	4.35	.112667	21
40	9.786089	2.72	9.898494	1.62	9.887594	4.35	0.112406	20
41	.786252	2.73	.898397	1.63	.887855	4.35	.112145	19
42	.786416	2.72	.898299	1.62	.888116	4.37	.111884	18
43	.786579	2.72	.898202	1.63	.888378	4.35	.111622	17
44	.786742	2.73	.898104	1.63	.888639	4.35	.111361	16
45	9.786906	2.72	9.898006	1.63	9.888900	4.35	0.111100	15
46	.787069	2.72	.897908	1.63	.889161	4.33	.110839	14
47	.787232	2.72	.897810	1.63	.889421	4.35	.110579	13
48	.787395	2.70	.897712	1.63	.889682	4.35	.110318	12
49	.787557	2.72	.897614	1.63	.889943	4.35	.110057	11
50	9.787720	2.72	9.897516	1.63	9.890204	4.35	0.109796	10
51	.787883	2.70	.897418	1.63	.890465	4.33	.109535	9
52	.788045	2.72	.897320	1.63	.890725	4.35	.109275	8
53	.788208	2.70	.897222	1.65	.890986	4.35	.109014	7
54	.788370	2.70	.897123	1.63	.891247	4.33	.108753	6
55	9.788532	2.70	9.897025	1.65	9.891507	4.35	0.108493	5
56	.788694	2.70	.896926	1.63	.891768	4.33	.108232	4
57	.788856	2.70	.896828	1.65	.892028	4.35	.107972	3
58	.789018	2.70	.896729	1.63	.892289	4.33	.107711	2
59	.789180	2.70	.896631	1.65	.892549	4.35	.107451	1
60	9.789342		9.896532		9.892810		0.107190	0
	Cos.	D. 1″.	Sin.	D. 1″.	Cot.	D. 1″.	Tan.	M.

127° 52°

38° 141°

M.	Sin.	D. 1″.	Cos.	D. 1″.	Tan.	D. 1″.	Cot.	
0	9.789342	2.70	9.896532	1.65	9.892810	4.33	0.107190	60
1	.789504	2.68	.896433	1.63	.893070	4.35	.106930	59
2	.789665	2.70	.896335	1.65	.893331	4.33	.106669	58
3	.789827	2.68	.896236	1.65	.893591	4.33	.106409	57
4	.789988	2.68	.896137	1.65	.893851	4.33	.106149	56
5	9.790149	2.68	9.896038	1.65	9.894111	4.35	0.105889	55
6	.790310	2.68	.895939	1.65	.894372	4.33	.105628	54
7	.790471	2.68	.895840	1.65	.894632	4.33	.105368	53
8	.790632	2.68	.895741	1.67	.894892	4.33	.105108	52
9	.790793	2.68	.895641	1.65	.895152	4.33	.104848	51
10	9.790954	2.68	9.895542	1.65	9.895412	4.33	0.104588	50
11	.791115	2.67	.895443	1.67	.895672	4.33	.104328	49
12	.791275	2.68	.895343	1.65	.895932	4.33	.104068	48
13	.791436	2.67	.895244	1.65	.896192	4.33	.103808	47
14	.791596	2.68	.895145	1.67	.896452	4.33	.103548	46
15	9.791757	2.67	9.895045	1.67	9.896712	4.32	0.103288	45
16	.791917	2.67	.894945	1.65	.896971	4.33	.103029	44
17	.792077	2.67	.894846	1.67	.897231	4.33	.102769	43
18	.792237	2.67	.894746	1.67	.897491	4.33	.102509	42
19	.792397	2.67	.894646	1.67	.897751	4.32	.102249	41
20	9.792557	2.65	9.894546	1.67	9.898010	4.33	0.101990	40
21	.792716	2.67	.894446	1.67	.898270	4.33	.101730	39
22	.792876	2.65	.894346	1.67	.898530	4.32	.101470	38
23	.793035	2.67	.894246	1.67	.898789	4.33	.101211	37
24	.793195	2.65	.894146	1.67	.899049	4.32	.100951	36
25	9.793354	2.67	9.894046	1.67	9.899308	4.33	0.100692	35
26	.793514	2.65	.893946	1.67	.899568	4.32	.100432	34
27	.793673	2.65	.893846	1.68	.899827	4.33	.100173	33
28	.793832	2.65	.893745	1.67	.900087	4.32	.099913	32
29	.793991	2.65	.893645	1.68	.900346	4.32	.099654	31
30	9.794150	2.63	9.893544	1.67	9.900605	4.32	0.099395	30
31	.794308	2.65	.893444	1.68	.900864	4.33	.099136	29
32	.794467	2.65	.893343	1.67	.901124	4.32	.098876	28
33	.794626	2.63	.893243	1.68	.901383	4.32	.098617	27
34	.794784	2.63	.893142	1.68	.901642	4.32	.098358	26
35	9.794942	2.65	9.893041	1.68	9.901901	4.32	0.098099	25
36	.795101	2.63	.892940	1.68	.902160	4.33	.097840	24
37	.795259	2.63	.892839	1.67	.902420	4.32	.097580	23
38	.795417	2.63	.892739	1.68	.902679	4.32	.097321	22
39	.795575	2.63	.892638	1.70	.902938	4.32	.097062	21
40	9.795733	2.63	9.892536	1.68	9.903197	4.32	0.096803	20
41	.795891	2.63	.892435	1.68	.903456	4.30	.096544	19
42	.796049	2.62	.892334	1.68	.903714	4.32	.096286	18
43	.796206	2.63	.892233	1.68	.903973	4.32	.096027	17
44	.796364	2.62	.892132	1.70	.904232	4.32	.095768	16
45	9.796521	2.63	9.892030	1.68	9.904491	4.32	0.095509	15
46	.796679	2.62	.891929	1.70	.904750	4.30	.095250	14
47	.796836	2.62	.891827	1.68	.905008	4.32	.094992	13
48	.796993	2.62	.891726	1.70	.905267	4.32	.094733	12
49	.797150	2.62	.891624	1.68	.905526	4.32	.094474	11
50	9.797307	2.62	9.891523	1.70	9.905785	4.30	0.094215	10
51	.797464	2.62	.891421	1.70	.906043	4.32	.093957	9
52	.797621	2.60	.891319	1.70	.906302	4.30	.093698	8
53	.797777	2.62	.891217	1.70	.906560	4.32	.093440	7
54	.797934	2.62	.891115	1.70	.906819	4.30	.093181	6
55	9.798091	2.60	9.891013	1.70	9.907077	4.32	0.092923	5
56	.798247	2.60	.890911	1.70	.907336	4.30	.092664	4
57	.798403	2.62	.890809	1.70	.907594	4.32	.092406	3
58	.798560	2.60	.890707	1.70	.907853	4.30	.092147	2
59	.798716	2.60	.890605	1.70	.908111	4.30	.091889	1
60	9.798872		9.890503		9.908369		0.091631	0
	Cos.	D. 1″.	Sin.	D. 1″.	Cot.	D. 1″.	Tan.	M

128° 51°

39° 140°

M.	Sin.	D. 1″.	Cos.	D. 1″.	Tan.	D. 1″.	Cot.	
0	9.798872	2.60	9.890503	1.72	9.908369	4.32	0.091631	60
1	.799028	2.60	.890400	1.70	.908628	4.30	.091372	59
2	.799184	2.58	.890298	1.72	.908886	4.30	.091114	58
3	.799339	2.60	.890195	1.70	.909144	4.30	.090856	57
4	.799495	2.60	.890093	1.72	.909402	4.30	.090598	56
5	9.799651	2.58	9.889990	1.70	9.909660	4.30	0.090340	55
6	.799806	2.60	.889888	1.72	.909918	4.32	.090082	54
7	.799962	2.58	.889785	1.72	.910177	4.30	.089823	53
8	.800117	2.58	.889682	1.72	.910435	4.30	.089565	52
9	.800272	2.58	.889579	1.70	.910693	4.30	.089307	51
10	9.800427	2.58	9.889477	1.72	9.910951	4.30	0.089049	50
11	.800582	2.58	.889374	1.72	.911209	4.30	.088791	49
12	.800737	2.58	.889271	1.72	.911467	4.30	.088533	48
13	.800892	2.58	.889168	1.73	.911725	4.28	.088275	47
14	.801047	2.57	.889064	1.72	.911982	4.30	.088018	46
15	9.801201	2.58	9.888961	1.72	9.912240	4.30	0.087760	45
16	.801356	2.58	.888858	1.72	.912498	4.30	.087502	44
17	.801511	2.57	.888755	1.73	.912756	4.30	.087244	43
18	.801665	2.57	.888651	1.72	.913014	4.28	.086986	42
19	.801819	2.57	.888548	1.73	.913271	4.30	.086729	41
20	9.801973	2.58	9.888444	1.72	9.913529	4.30	0.086471	40
21	.802128	2.57	.888341	1.73	.913787	4.28	.086213	39
22	.802282	2.57	.888237	1.72	.914044	4.30	.085956	38
23	.802436	2.55	.888134	1.73	.914302	4.30	.085698	37
24	.802589	2.57	.888030	1.73	.914560	4.28	.085440	36
25	9.802743	2.57	9.887926	1.73	9.914817	4.30	0.085183	35
26	.802897	2.55	.887822	1.73	.915075	4.28	.084925	34
27	.803050	2.57	.887718	1.73	.915332	4.30	.084668	33
28	.803204	2.55	.887614	1.73	.915590	4.28	.084410	32
29	.803357	2.57	.887510	1.73	.915847	4.28	.084153	31
30	9.803511	2.55	9.887406	1.73	9.916104	4.30	0.083896	30
31	.803664	2.55	.887302	1.73	.916362	4.28	.083638	29
32	.803817	2.55	.887198	1.75	.916619	4.30	.083381	28
33	.803970	2.55	.887093	1.73	.916877	4.28	.083123	27
34	.804123	2.55	.886989	1.73	.917134	4.28	.082866	26
35	9.804276	2.53	9.886885	1.75	9.917391	4.28	0.082609	25
36	.804428	2.55	.886780	1.73	.917648	4.30	.082352	24
37	.804581	2.55	.886676	1.75	.917906	4.28	.082094	23
38	.804734	2.53	.886571	1.75	.918163	4.28	.081837	22
39	.804886	2.55	.886466	1.73	.918420	4.28	.081580	21
40	9.805039	2.53	9.886362	1.75	9.918677	4.28	0.081323	20
41	.805191	2.53	.886257	1.75	.918934	4.28	.081066	19
42	.805343	2.53	.886152	1.75	.919191	4.28	.080809	18
43	.805495	2.53	.886047	1.75	.919448	4.28	.080552	17
44	.805647	2.53	.885942	1.75	.919705	4.28	.080295	16
45	9.805799	2.53	9.885837	1.75	9.919962	4.28	0.080038	15
46	.805951	2.53	.885732	1.75	.920219	4.28	.079781	14
47	.806103	2.52	.885627	1.75	.920476	4.28	.079524	13
48	.806254	2.53	.885522	1.77	.920733	4.28	.079267	12
49	.806406	2.52	.885416	1.75	.920990	4.28	.079010	11
50	9.806557	2.53	9.885311	1.77	9.921247	4.27	0.078753	10
51	.806709	2.52	.885205	1.75	.921503	4.28	.078497	9
52	.806860	2.52	.885100	1.77	.921760	4.28	.078240	8
53	.807011	2.53	.884994	1.75	.922017	4.28	.077983	7
54	.807163	2.52	.884889	1.77	.922274	4.27	.077726	6
55	9.807314	2.52	9.884783	1.77	9.922530	4.28	0.077470	5
56	.807465	2.50	.884677	1.75	.922787	4.28	.077213	4
57	.807615	2.52	.884572	1.77	.923044	4.27	.076956	3
58	.807766	2.52	.884466	1.77	.923300	4.28	.076700	2
59	.807917	2.50	.884360	1.77	.923557	4.23	.076443	1
60	9.808067		9.884254		9.923814		0.076186	0
	Cos.	D. 1″.	Sin.	D. 1″.	Cot.	D. 1″.	Tan.	M.

129° 50°

40° | 139°

M.	Sin.	D. 1″.	Cos.	D. 1″.	Tan.	D. 1″.	Cot.	
0	9.808067	2.52	9.884254	1.77	9.923814	4.27	0.076186	60
1	.808218	2.50	.884148	1.77	.924070	4.28	.075930	59
2	.808368	2.52	.884042	1.77	.924327	4.27	.075673	58
3	.808519	2.50	.883936	1.78	.924583	4.28	.075417	57
4	.808669	2.50	.883829	1.77	.924840	4.27	.075160	56
5	9.808819	2.50	9.883723	1.77	9.925096	4.27	0.074904	55
6	.808969	2.50	.883617	1.78	.925352	4.28	.074648	54
7	.809119	2.50	.883510	1.77	.925609	4.27	.074391	53
8	.809269	2.50	.883404	1.78	.925865	4.28	.074135	52
9	.809419	2.50	.883297	1.77	.926122	4.27	.073878	51
10	9.809569	2.48	9.883191	1.78	9.926378	4.27	0.073622	50
11	.809718	2.50	.883084	1.78	.926634	4.27	.073366	49
12	.809868	2.48	.882977	1.77	.926890	4.28	.073110	48
13	.810017	2.50	.882871	1.78	.927147	4.27	.072853	47
14	.810167	2.48	.882764	1.78	.927403	4.27	.072597	46
15	9.810316	2.48	9.882657	1.78	9.927659	4.27	0.072341	45
16	.810465	2.48	.882550	1.78	.927915	4.27	.072085	44
17	.810614	2.48	.882443	1.78	.928171	4.27	.071829	43
18	.810763	2.48	.882336	1.78	.928427	4.28	.071573	42
19	.810912	2.48	.882229	1.80	.928684	4.27	.071316	41
20	9.811061	2.48	9.882121	1.78	9.928940	4.27	0.071060	40
21	.811210	2.47	.882014	1.78	.929196	4.27	.070804	39
22	.811358	2.48	.881907	1.80	.929452	4.27	.070548	38
23	.811507	2.47	.881799	1.78	.929708	4.27	.070292	37
24	.811655	2.48	.881692	1.80	.929964	4.27	.070036	36
25	9.811804	2.47	9.881584	1.78	9.930220	4.25	0.069780	35
26	.811952	2.47	.881477	1.80	.930475	4.27	.069525	34
27	.812100	2.47	.881369	1.80	.930731	4.27	.069269	33
28	.812248	2.47	.881261	1.80	.930987	4.27	.069013	32
29	.812396	2.47	.881153	1.78	.931243	4.27	.068757	31
30	9.812544	2.47	9.881046	1.80	9.931499	4.27	0.068501	30
31	.812692	2.47	.880938	1.80	.931755	4.25	.068245	29
32	.812840	2.47	.880830	1.80	.932010	4.27	.067990	28
33	.812988	2.45	.880722	1.82	.932266	4.27	.067734	27
34	.813135	2.47	.880613	1.80	.932522	4.27	.067478	26
35	9.813283	2.45	9.880505	1.80	9.932778	4.25	0.067222	25
36	.813430	2.47	.880397	1.80	.933033	4.27	.066967	24
37	.813578	2.45	.880289	1.82	.933289	4.27	.066711	23
38	.813725	2.45	.880180	1.80	.933545	4.25	.066455	22
39	.813872	2.45	.880072	1.82	.933800	4.27	.066200	21
40	9.814019	2.45	9.879963	1.80	9.934056	4.25	0.065944	20
41	.814166	2.45	.879855	1.82	.934311	4.27	.065689	19
42	.814313	2.45	.879746	1.82	.934567	4.25	.065433	18
43	.814460	2.45	.879637	1.80	.934822	4.27	.065178	17
44	.814607	2.43	.879529	1.82	.935078	4.25	.064922	16
45	9.814753	2.45	9.879420	1.82	9.935333	4.27	0.064667	15
46	.814900	2.43	.879311	1.82	.935589	4.25	.064411	14
47	.815046	2.45	.879202	1.82	.935844	4.27	.064156	13
48	.815193	2.43	.879093	1.82	.936100	4.25	.063900	12
49	.815339	2.43	.878984	1.82	.936355	4.27	.063645	11
50	9.815485	2.45	9.878875	1.82	9.936611	4.25	0.063389	10
51	.815632	2.43	.878766	1.83	.936866	4.25	.063134	9
52	.815778	2.43	.878656	1.82	.937121	4.27	.062879	8
53	.815924	2.42	.878547	1.82	.937377	4.25	.062623	7
54	.816069	2.43	.878438	1.83	.937632	4.25	.062368	6
55	9.816215	2.43	9.878328	1.82	9.937887	4.25	0.062113	5
56	.816361	2.43	.878219	1.83	.938142	4.27	.061858	4
57	.816507	2.42	.878109	1.83	.938398	4.25	.061602	3
58	.816652	2.43	.877999	1.82	.938653	4.25	.061347	2
59	.816798	2.42	.877890	1.83	.938908	4.25	.061092	1
60	9.816943		9.877780		9.939163		0.060837	0
	Cos.	D. 1″.	Sin.	D. 1″.	Cot.	D. 1″.	Tan.	M.

130° | 94°

41° 138°

M.	Sin.	D. 1″.	Cos.	D. 1″.	Tan.	D. 1″.	Cot.	
0	9.816943	2.42	9.877780	1.83	9.939163	4.25	0.060837	60
1	.817088	2.42	.877670	1.83	.939418	4.25	.060582	59
2	.817233	2.43	.877560	1.83	.939673	4.25	.060327	58
3	.817379	2.42	.877450	1.83	.939928	4.25	.060072	57
4	.817524	2.40	.877340	1.83	.940183	4.27	.059817	56
5	9.817668	2.42	9.877230	1.83	9.940439	4.25	0.059561	55
6	.817813	2.42	.877120	1.83	.940694	4.25	.059306	54
7	.817958	2.42	.877010	1.85	.940949	4.25	.059051	53
8	.818103	2.40	.876899	1.83	.941204	4.25	.058796	52
9	.818247	2.42	.876789	1.85	.941459	4.23	.058541	51
10	9.818392	2.40	9.876678	1.83	9.941713	4.25	0.058287	50
11	.818536	2.42	.876568	1.85	.941968	4.25	.058032	49
12	.818681	2.40	.876457	1.83	.942223	4.25	.057777	48
13	.818825	2.40	.876347	1.85	.942478	4.25	.057522	47
14	.818969	2.40	.876236	1.85	.942733	4.25	.057267	46
15	9.819113	2.40	9.876125	1.85	9.942988	4.25	0.057012	45
16	.819257	2.40	.876014	1.83	.943243	4.25	.056757	44
17	.819401	2.40	.875904	1.85	.943498	4.23	.056502	43
18	.819545	2.40	.875793	1.85	.943752	4.25	.056248	42
19	.819689	2.38	.875682	1.85	.944007	4.25	.055993	41
20	9.819832	2.40	9.875571	1.87	9.944262	4.25	0.055738	40
21	.819976	2.40	.875459	1.85	.944517	4.23	.055483	39
22	.820120	2.38	.875348	1.85	.944771	4.25	.055229	38
23	.820263	2.38	.875237	1.85	.945026	4.25	.054974	37
24	.820406	2.40	.875126	1.87	.945281	4.23	.054719	36
25	9.820550	2.38	9.875014	1.85	9.945535	4.25	0.054465	35
26	.820693	2.38	.874903	1.87	.945790	4.25	.054210	34
27	.820836	2.38	.874791	1.85	.946045	4.23	.053955	33
28	.820979	2.38	.874680	1.87	.946299	4.25	.053701	32
29	.821122	2.38	.874568	1.87	.946554	4.23	.053446	31
30	9.821265	2.37	9.874456	1.87	9.946808	4.25	0.053192	30
31	.821407	2.38	.874344	1.87	.947063	4.25	.052937	29
32	.821550	2.38	.874232	1.85	.947318	4.23	.052682	28
33	.821693	2.37	.874121	1.87	.947572	4.25	.052428	27
34	.821835	2.37	.874009	1.88	.947827	4.23	.052173	26
35	9.821977	2.38	9.873896	1.87	9.948081	4.23	0.051919	25
36	.822120	2.37	.873784	1.87	.948335	4.25	.051665	24
37	.822262	2.37	.873672	1.87	.948590	4.23	.051410	23
38	.822404	2.37	.873560	1.87	.948844	4.25	.051156	22
39	.822546	2.37	.873448	1.88	.949099	4.23	.050901	21
40	9.822688	2.37	9.873335	1.87	9.949353	4.25	0.050647	20
41	.822830	2.37	.873223	1.88	.949608	4.23	.050392	19
42	.822972	2.37	.873110	1.87	.949862	4.23	.050138	18
43	.823114	2.35	.872998	1.88	.950116	4.25	.049884	17
44	.823255	2.37	.872885	1.88	.950371	4.23	.049629	16
45	9.823397	2.37	9.872772	1.88	9.950625	4.23	0.049375	15
46	.823539	2.35	.872659	1.87	.950879	4.23	.049121	14
47	.823680	2.35	.872547	1.88	.951133	4.25	.048867	13
48	.823821	2.37	.872434	1.88	.951388	4.23	.048612	12
49	.823963	2.35	.872321	1.88	.951642	4.23	.048358	11
50	9.824104	2.35	9.872208	1.88	9.951896	4.23	0.048104	10
51	.824245	2.35	.872095	1.90	.952150	4.25	.047850	9
52	.824386	2.35	.871981	1.88	.952405	4.23	.047595	8
53	.824527	2.35	.871868	1.88	.952659	4.23	.047341	7
54	.824668	2.33	.871755	1.90	.952913	4.23	.047087	6
55	9.824808	2.35	9.871641	1.88	9.953167	4.23	0.046833	5
56	.824949	2.35	.871528	1.90	.953421	4.23	.046579	4
57	.825090	2.33	.871414	1.88	.953675	4.23	.046325	3
58	.825230	2.35	.871301	1.90	.953929	4.23	.046071	2
59	.825371	2.33	.871187	1.90	.954183	4.23	.045817	1
60	9.825511		9.871073		9.954437		0.045563	0
	Cos.	D. 1″.	Sin.	D. 1″.	Cot.	D. 1″.	Tan.	M.

131° 48°

42° 137°

M.	Sin.	D. 1″.	Cos.	D. 1″.	Tan.	D. 1″.	Cot.	
0	9.825511	2.33	9.871073	1.88	9.954437	4.23	0.045563	60
1	.825651	2.33	.870960	1.90	.954691	4.25	.045309	59
2	.825791	2.33	.870846	1.90	.954946	4.23	.045054	58
3	.825931	2.33	.870732	1.90	.955200	4.23	.044800	57
4	.826071	2.33	.870618	1.90	.955454	4.23	.044546	56
5	9.826211	2.33	9.870504	1.90	9.955708	4.22	0.044292	55
6	.826351	2.33	.870390	1.90	.955961	4.23	.044039	54
7	.826491	2.33	.870276	1.92	.956215	4.23	.043785	53
8	.826631	2.32	.870161	1.90	.956469	4.23	.043531	52
9	.826770	2.33	.870047	1.90	.956723	4.23	.043277	51
10	9.826910	2.32	9.869933	1.92	9.956977	4.23	0.043023	50
11	.827049	2.33	.869818	1.90	.957231	4.23	.042769	49
12	.827189	2.32	.869704	1.92	.957485	4.23	.042515	48
13	.827328	2.32	.869589	1.92	.957739	4.23	.042261	47
14	.827467	2.32	.869474	1.90	.957993	4.23	.042007	46
15	9.827606	2.32	9.869360	1.92	9.958247	4.22	0.041753	45
16	.827745	2.32	.869245	1.92	.958500	4.23	.041500	44
17	.827884	2.32	.869130	1.92	.958754	4.23	.041246	43
18	.828023	2.32	.869015	1.92	.959008	4.23	.040992	42
19	.828162	2.32	.868900	1.92	.959262	4.23	.040738	41
20	9.828301	2.30	9.868785	1.92	9.959516	4.22	0.040484	40
21	.828439	2.32	.868670	1.92	.959769	4.23	.040231	39
22	.828578	2.30	.868555	1.92	.960023	4.23	.039977	38
23	.828716	2.32	.868440	1.93	.960277	4.22	.039723	37
24	.828855	2.30	.868324	1.92	.960530	4.23	.039470	36
25	9.828993	2.30	9.868209	1.93	9.960784	4.23	0.039216	35
26	.829131	2.30	.868093	1.92	.961038	4.23	.038962	34
27	.829269	2.30	.867978	1.93	.961292	4.22	.038708	33
28	.829407	2.30	.867862	1.92	.961545	4.23	.038455	32
29	.829545	2.30	.867747	1.93	.961799	4.22	.038201	31
30	9.829683	2.30	9.867631	1.93	9.962052	4.23	0.037948	30
31	.829821	2.30	.867515	1.93	.962306	4.23	.037694	29
32	.829959	2.30	.867399	1.93	.962560	4.22	.037440	28
33	.830097	2.28	.867283	1.93	.962813	4.23	.037187	27
34	.830234	2.30	.867167	1.93	.963067	4.22	.036933	26
35	9.830372	2.28	9.867051	1.93	9.963320	4.23	0.036680	25
36	.830509	2.28	.866935	1.93	.963574	4.23	.036426	24
37	.830646	2.30	.866819	1.93	.963828	4.22	.036172	23
38	.830784	2.28	.866703	1.95	.964081	4.23	.035919	22
39	.830921	2.28	.866586	1.93	.964335	4.22	.035665	21
40	9.831058	2.28	9.866470	1.95	9.964588	4.23	0.035412	20
41	.831195	2.28	.866353	1.93	.964842	4.22	.035158	19
42	.831332	2.28	.866237	1.95	.965095	4.23	.034905	18
43	.831469	2.28	.866120	1.93	.965349	4.22	.034651	17
44	.831606	2.27	.866004	1.95	.965602	4.22	.034398	16
45	9.831742	2.28	9.865887	1.95	9.965855	4.23	0.034145	15
46	.831879	2.27	.865770	1.95	.966109	4.22	.033891	14
47	.832015	2.28	.865653	1.95	.966362	4.23	.033638	13
48	.832152	2.27	.865536	1.95	.966616	4.22	.033384	12
49	.832288	2.28	.865419	1.95	.966869	4.23	.033131	11
50	9.832425	2.27	9.865302	1.95	9.967123	4.22	0.032877	10
51	.832561	2.27	.865185	1.95	.967376	4.22	.032624	9
52	.832697	2.27	.865068	1.97	.967629	4.23	.032371	8
53	.832833	2.27	.864950	1.95	.967883	4.22	.032117	7
54	.832969	2.27	.864833	1.95	.968136	4.22	.031864	6
55	9.833105	2.27	9.864716	1.97	9.968389	4.23	0.031611	5
56	.833241	2.27	.864598	1.95	.968643	4.22	.031357	4
57	.833377	2.25	.864481	1.97	.968896	4.22	.031104	3
58	.833512	2.27	.864363	1.97	.969149	4.23	.030851	2
59	.833648	2.25	.864245	1.97	.969403	4.22	.030597	1
60	9.833783		9.864127		9.969656		0.030344	0
	Cos.	D. 1″.	Sin.	D. 1″.	Cot.	D. 1″.	Tan.	M.

43° 13

M.	Sin.	D. 1″.	Cos.	D. 1″.	Tan.	D. 1″.	Cot.	
0	9.833783	2.27	9.864127	1.95	9.969656	4.22	0.030344	6
1	.833919	2.25	.864010	1.97	.969909	4.22	.030091	5
2	.834054	2.25	.863892	1.97	.970162	4.23	.029838	5
3	.834189	2.27	.863774	1.97	.970416	4.22	.029584	5
4	.834325	2.25	.863656	1.97	.970669	4.22	.029331	5
5	9.834460	2.25	9.863538	1.98	9.970922	4.22	0.029078	5
6	.834595	2.25	.863419	1.97	.971175	4.23	.028825	5
7	.834730	2.25	.863301	1.97	.971429	4.22	.028571	5
8	.834865	2.23	.863183	1.98	.971682	4.22	.028318	5
9	.834999	2.25	.863064	1.97	.971935	4.22	.028065	5
10	9.835134	2.25	9.862946	1.98	9.972188	4.22	0.027812	5
11	.835269	2.23	.862827	1.97	.972441	4.23	.027559	4
12	.835403	2.25	.862709	1.98	.972695	4.22	.027305	4
13	.835538	2.23	.862590	1.98	.972948	4.22	.027052	4
14	.835672	2.25	.862471	1.97	.973201	4.22	.026799	4
15	9.835807	2.23	9.862353	1.98	9.973454	4.22	0.026546	4
16	.835941	2.23	.862234	1.98	.973707	4.22	.026293	4
17	.836075	2.23	.862115	1.98	.973960	4.22	.026040	4
18	.836209	2.23	.861996	1.98	.974213	4.22	.025787	4
19	.836343	2.23	.861877	1.98	.974466	4.23	.025534	4
20	9.836477	2.23	9.861758	2.00	9.974720	4.22	0.025280	4
21	.836611	2.23	.861638	1.98	.974973	4.22	.025027	3
22	.836745	2.22	.861519	1.98	.975226	4.22	.024774	3
23	.836878	2.23	.861400	2.00	.975479	4.22	.024521	3
24	.837012	2.23	.861280	1.98	.975732	4.22	.024268	3
25	9.837146	2.22	9.861161	2.00	9.975985	4.22	0.024015	3
26	.837279	2.22	.861041	1.98	.976238	4.22	.023762	3
27	.837412	2.23	.860922	2.00	.976491	4.22	.023509	3
28	.837546	2.22	.860802	2.00	.976744	4.22	.023256	3
29	.837679	2.22	.860682	2.00	.976997	4.22	.023003	3
30	9.837812	2.22	9.860562	2.00	9.977250	4.22	0.022750	3
31	.837945	2.22	.860442	2.00	.977503	4.22	.022497	2
32	.838078	2.22	.860322	2.00	.977756	4.22	.022244	2
33	.838211	2.22	.860202	2.00	.978009	4.22	.021991	2
34	.838344	2.22	.860082	2.00	.978262	4.22	.021738	2
35	9.838477	2.22	9.859962	2.00	9.978515	4.22	0.021485	2
36	.838610	2.20	.859842	2.02	.978768	4.22	.021232	2
37	.838742	2.22	.859721	2.00	.979021	4.22	.020979	2
38	.838875	2.20	.859601	2.02	.979274	4.22	.020726	2
39	.839007	2.22	.859480	2.00	.979527	4.22	.020473	2
40	9.839140	2.20	9.859360	2.02	9.979780	4.22	0.020220	2
41	.839272	2.20	.859239	2.00	.980033	4.22	.019967	1
42	.839404	2.20	.859119	2.02	.980286	4.20	.019714	1
43	.839536	2.20	.858998	2.02	.980538	4.22	.019462	1
44	.839668	2.20	.858877	2.02	.980791	4.22	.019209	1
45	9.839800	2.20	9.858756	2.02	9.981044	4.22	0.018956	1
46	.839932	2.20	.858635	2.02	.981297	4.22	.018703	1
47	.840064	2.20	.858514	2.02	.981550	4.22	.018450	1
48	.840196	2.20	.858393	2.02	.981803	4.22	.018197	1
49	.840328	2.18	.858272	2.02	.982056	4.22	.017944	1
50	9.840459	2.20	9.858151	2.03	9.982309	4.22	0.017691	1
51	.840591	2.18	.858029	2.02	.982562	4.20	.017438	
52	.840722	2.20	.857908	2.03	.982814	4.22	.017186	
53	.840854	2.18	.857786	2.02	.983067	4.22	.016933	
54	.840985	2.18	.857665	2.03	.983320	4.22	.016680	
55	9.841116	2.18	9.857543	2.02	9.983573	4.22	0.016427	
56	.841247	2.18	.857422	2.03	.983826	4.22	.016174	
57	.841378	2.18	.857300	2.03	.984079	4.22	.015921	
58	.841509	2.18	.857178	2.03	.984332	4.20	.015668	
59	.841640	2.18	.857056	2.03	.984584	4.22	.015416	
60	9.841771		9.856934		9.984837		0.015163	
	Cos.	D. 1″.	Sin.	D. 1″.	Cot.	D. 1″.	Tan.	M

44° 135°

M.	Sin.	D. 1″.	Cos.	D. 1″.	Tan.	D. 1″.	Cot.	
0	9.841771	2.18	9.856934	2.03	9.984837	4.22	0.015163	60
1	.841902	2.18	.856812	2.03	.985090	4.22	.014910	59
2	.842033	2.17	.856690	2.03	.985343	4.22	.014657	58
3	.842163	2.18	.856568	2.03	.985596	4.20	.014404	57
4	.842294	2.17	.856446	2.05	.985848	4.22	.014152	56
5	9.842424	2.18	9.856323	2.03	9.986101	4.22	0.013899	55
6	.842555	2.17	.856201	2.05	.986354	4.22	.013646	54
7	.842685	2.17	.856078	2.03	.986607	4.22	.013393	53
8	.842815	2.18	.855956	2.05	.986860	4.20	.013140	52
9	.842946	2.17	.855833	2.03	.987112	4.22	.012888	51
10	9.843076	2.17	9.855711	2.05	9.987365	4.22	0.012635	50
11	.843206	2.17	.855588	2.05	.987618	4.22	.012382	49
12	.843336	2.17	.855465	2.05	.987871	4.20	.012129	48
13	.843466	2.15	.855342	2.05	.988123	4.22	.011877	47
14	.843595	2.17	.855219	2.05	.988376	4.22	.011624	46
15	9.843725	2.17	9.855096	2.05	9.988629	4.22	0.011371	45
16	.843855	2.15	.854973	2.05	.988882	4.20	.011118	44
17	.843984	2.17	.854850	2.05	.989134	4.22	.010866	43
18	.844114	2.15	.854727	2.07	.989387	4.22	.010613	42
19	.844243	2.15	.854603	2.05	.989640	4.22	.010360	41
20	9.844372	2.17	9.854480	2.07	9.989893	4.20	0.010107	40
21	.844502	2.15	.854356	2.05	.990145	4.22	.009855	39
22	.844631	2.15	.854233	2.07	.990398	4.22	.009602	38
23	.844760	2.15	.854109	2.05	.990651	4.20	.009349	37
24	.844889	2.15	.853986	2.07	.990903	4.22	.009097	36
25	9.845018	2.15	9.853862	2.07	9.991156	4.22	0.008844	35
26	.845147	2.15	.853738	2.07	.991409	4.22	.008591	34
27	.845276	2.15	.853614	2.07	.991662	4.20	.008338	33
28	.845405	2.13	.853490	2.07	.991914	4.22	.008086	32
29	.845533	2.15	.853366	2.07	.992167	4.22	.007833	31
30	9.845662	2.13	9.853242	2.07	9.992420	4.20	0.007580	30
31	.845790	2.15	.853118	2.07	.992672	4.22	.007328	29
32	.845919	2.13	.852994	2.08	.992925	4.22	.007075	28
33	.846047	2.13	.852869	2.07	.993178	4.22	.006822	27
34	.846175	2.15	.852745	2.08	.993431	4.20	.006569	26
35	9.846304	2.13	9.852620	2.07	9.993683	4.22	0.006317	25
36	.846432	2.13	.852496	2.08	.993936	4.22	.006064	24
37	.846560	2.13	.852371	2.07	.994189	4.20	.005811	23
38	.846688	2.13	.852247	2.08	.994441	4.22	.005559	22
39	.846816	2.13	.852122	2.08	.994694	4.22	.005306	21
40	9.846944	2.12	9.851997	2.08	9.994947	4.20	0.005053	20
41	.847071	2.13	.851872	2.08	.995199	4.22	.004801	19
42	.847199	2.13	.851747	2.08	.995452	4.22	.004548	18
43	.847327	2.12	.851622	2.08	.995705	4.20	.004295	17
44	.847454	2.13	.851497	2.08	.995957	4.22	.004043	16
45	9.847582	2.12	9.851372	2.10	9.996210	4.22	0.003790	15
46	.847709	2.12	.851246	2.08	.996463	4.20	.003537	14
47	.847836	2.13	.851121	2.08	.996715	4.22	.003285	13
48	.847964	2.12	.850996	2.10	.996968	4.22	.003032	12
49	.848091	2.12	.850870	2.08	.997221	4.20	.002779	11
50	9.848218	2.12	9.850745	2.10	9.997473	4.22	0.002527	10
51	.848345	2.12	.850619	2.10	.997726	4.22	.002274	9
52	.848472	2.12	.850493	2.08	.997979	4.20	.002021	8
53	.848599	2.12	.850368	2.10	.998231	4.22	.001769	7
54	.848726	2.10	.850242	2.10	.998484	4.22	.001516	6
55	9.848852	2.12	9.850116	2.10	9.998737	4.20	0.001263	5
56	.848979	2.12	.849990	2.10	.998989	4.22	.001011	4
57	.849106	2.10	.849864	2.10	.999242	4.22	.000758	3
58	.849232	2.12	.849738	2.12	.999495	4.20	.000505	2
59	.849359	2.10	.849611	2.10	.999747	4.22	.000253	1
60	9.849485		9.849485		0.000000		0.000000	0
	Cos.	D. 1″.	Sin.	D. 1″.	Cot.	D. 1″.	Tan.	M.

134° 45°

APPENDIX A

FIRST AID IN CASE OF ACCIDENT

All the data on First Aid are quoted from *Bull.* of the U. S. Health Service, by the courtesy of the Department, which was glad to cooperate to make the data available for emergencies.

Condensed Index

U. S. HEALTH SERVICE BULL. 17

BY SURGEON R. M. WOODWARD

Rules to Be Observed in Time of Accident

"1. Give the patient air.

"2. Lay the patient down, head lower than the body.

"3. Rip the clothes off the injured part.

"4. In removing a coat or shirt, first release the good arm, then the injured one.

"5. Turn the head to one side to allow vomited matters to escape from the mouth.

"6. Do not give whisky to the patient. If he can swallow, and needs a stimulant, give coffee, tea, hot milk, or hot water.

"7. Then follow directions given elsewhere in this book.

A List of Dont's

"Don't fail to send for the doctor. He knows best.

"Don't leave the patient in order to go for the doctor if there is anyone you can send. He may need your moral encouragement if nothing more.

"Don't get excited. An appearance of agitation on your part will discourage the patient.

"Don't hold an injured person on his feet, nor require him to sit in a chair. He will be better off and less apt to faint if he lies down, preferably with the head low.

"If you have a first-aid chest, and a bottle of medicine is exhausted, don't wait until you need it again before having the bottle filled.

"Don't put your fingers on a wound. They are covered with germs, and you will almost surely infect the wound.

"Don't use a spider web or a quid of tobacco on a wound. They are filthy, do no good, and are very apt to infect the wound. The same thing is true to a less extent in regard to salves of various kinds.

"Don't place cotton next to a wound. Always keep at least one layer of gauze or boiled cloth between the cotton and the raw surface. The cotton sticks to the wound and is very difficult to remove.

"Don't apply bandages too tightly.

"Don't remove a dressing to see how a wound looks. Let the doctor do that.

"Don't sit down at the bedside and discuss with the callers all of the horrible accidents you ever heard of. Your conversation will not be appreciated by the patient.

Minor Accidents

"Bruises, sprains, foreign matter in eyes, ears, nose, and throat.

Bruises and Contusions

"A bruise or contusion is an injury where the tissues beneath the skin have been torn but the skin itself has not been opened. Blood oozes out of the injured vessels, but cannot escape, as the skin is still intact. The symptoms are swelling, tenderness, and a feeling of soreness or pain. Discoloration of the skin occurs quickly in superficial contusions and in places where loose tissue abounds, but only after days when the injury is deep seated. This discoloration is at first red and then, successively, purple, black, green, and yellow. This play of colors is due to the changes which take place in the blood while undergoing absorption.

"**Treatment.**—A pad of gauze or soft towel should be tighly bandaged over the injured part to stop hemorrhage, after which cold should be applied except in old or feeble persons or where the contusion is extensive. In the latter case heat is best, as cold might cause gangrene. Evaporating solutions, such as witch hazel, a 15 % solution of alcohol in water, or a saturated solution of Epsom salt, are often found of great benefit. A contusion should never be opened except in rare cases when it is necessary to stop persistent bleeding. If an opening is made through the skin, germs are liable to enter and cause severe inflammation, resulting in the formation of pus.

"**Sprains.**—A sprain is a stretching or wrenching of a joint. The joints most frequently affected are the ankle, wrist, knee, and shoulder.

"The symptoms and signs are pain, swelling, impairment or loss of motion, and discoloration from effusion of blood. When there is much swelling it may be difficult to determine whether sprain or fracture, or both, are present.

"It is sometimes very difficult to determine whether an injury near a joint is a sprain, a bruise, a broken bone, or all combined; and if there is doubt, the case should be treated as a broken bone. Injuries about the ankle joint are especially confusing, and sometimes the *x*-ray shows a fracture that could not have been detected in any other way. It should also be understood that a sprain, particularly if some of the soft parts about the joint are torn, may be much longer in being restored to a normal condition than if a simple break of the bone had occurred without other injury.

"**Treatment.**—Either hot or cold applications are good first-aid measures, but they should be distinctly either hot or cold, and not tepid. Soaking the part for half an hour several times a day in water as hot as can be borne, and gently rubbing the skin, are excellent. If it is more convenient to apply a bag of ice, this can be used, but the heat and cold should not alternate. Propping the part up on pillows assists. If there is much pain, great relief is obtained by surrounding the joint with a thick layer of cotton and applying a plaster bandage. The circulation of the lower part of the limb should be watched, and if found to be impaired the bandage should be cut from above downward and the sides spread apart to relieve any constriction that may be present. After the swelling has subsided somewhat, rubbing with any kind of liniment or with alcohol will help, but it is the rubbing more than the liniment that does the good.

"It is popular belief among laymen that a large quantity of liniment, perhaps applied on flannel cloth, is all that is necessary, and that the rubbing is only of secondary importance. This is a decided mistake. Later on the part should be grasped and gently moved in various directions, making what is known as passive motion. In some cases this is inadvisable and the patient appears to do better with the part at rest, which can be obtained by strapping the joint with strips of sticking plaster or placing the limb in a splint. The black and blue condition of the skin that sometimes appears will gradually subside as the part gets better.

Foreign Bodies in the Eye, Ear, Nose, and Throat

"**Foreign Bodies in the Eye.**—When a piece of steel, a cinder, or any foreign body enters the eye, nature at once floods the eye with tears in an

endeavor to wash the offending agent away, and frequently succeeds. Sometimes, however, the foreign body is embedded in the eyeball, the lid, or other part of the eye, or keeps moving about from one part to another without escaping; then assistance is necessary.

"Occasionally drawing the upper lid well down with the fingers, and allowing the lashes of the lower lid to act as a brush, will remove the body if it is not tightly embedded. Usually, however, it is necessary to invert the upper lid; in other words, turn it inside out. This is not difficult with a little practice. The upper eyelid contains a piece of cartilage or gristle along its lower edge which makes it easy to turn. To invert the eyelid face the patient, or stand behind him as seems more convenient; have him look well down toward the floor; take hold of the lashes of the upper lid with the fingers and thumb of one hand; they lay entirely across the middle of the eyelid a wooden toothpick, match, knitting needle, lead pencil, or other thin object (Fig. 1); press it downward, and at the same time gently pull the lashes upward, when the lid will suddenly turn inside out (Fig. 2).

FIG. 1.

FIG. 2.

Drawing down the lower lid by simply pressing upon it will expose its inside surface. If the foreign body is seen, it should be very gently removed with the corner of a handkerchief. If it is partly embedded in the eyelid, it may be possible to dislodge it gently with a wooden toothpick or other similar object. If the foreign body is on the eyeball, it sometimes requires a good light, good eyesight, and even a magnifying glass to detect it. If found, it should be removed with a handkerchief or other soft material, but if embedded too tightly to be removed in this manner, it is best for the layman not to attempt anything further for fear of greater injury to the eye. Under such circumstances one or both of the eyes should be snugly bandaged with soft lightproof material, such as red flannel and the doctor should be called as soon as possible. The patient should be cautioned not to wink his eyes, as all motion will increase the irritation.

"If you have succeeded in removing the body, and the eye appears very red, a little sweet oil dropped in will be very soothing. It should be remembered that the scratching of the eyeball makes it feel as if the body were still present after its removal. The old household remedy of dropping a flaxseed into the eye in the hope that in slipping about it may dislodge the body is said by specialists to do no good, and may do harm.

"**Foreign Bodies in the Ear.**—Children occasionally place buttons or similar objects in the ear. If near the outlet, they can sometimes be removed (in the absence of suitable instruments) by gently passing along one side a crochet needle or other similar implement. It should be remembered, however, that the drum of the ear, which is extremely delicate, and means so much to the child in the future, is only a short distance inside, and any

effort of this kind made by the layman should be very gentle indeed. A stream of water from a small syringe may wash the object out. If these measures do not succeed, wait for the doctor by all means. Sometimes an insect crawls into the ear. The actual physical danger is less than the mental horror, as the insect soon dies. A little sweet oil dropped into the ear may cause the insect to back out to free itself from the unpleasant predicament; if not the oil will kill it.

"**Foreign Bodies in the Nose.**—If near enough to the nostril to be seen the body may possibly be expelled by compressing the other nostril and having the patient blow his nose hard. A fountain syringe placed 1′ above the head, the nozzle of the syringe inserted in the clear nostril, and the patient's face looking somewhat downward will cause the water to flow gently in at one side of the nose and out at the other side, and may dislodge the object. A crochet needle may be gently tried as described for the ear. All these things failing, wait for the doctor.

"**Foreign Bodies in the Throat.**—If the body can be seen by holding the tongue down with a spoon or by drawing the tongue out with a towel, it can sometimes be hooked out by means of a finger passed well in. If the body is in the windpipe, this will be manifested by violent coughing, which may dislodge it. Inverting the patient and slapping his back may be tried. If these measures do not succeed, then use every effort to quiet the patient. and if practicable send for a physician. If the body is in the gullet on the way to the stomach, vomiting may bring it up, and this can be excited by tickling the throat, or using some of the simple vomiting agents mentioned in the data on poisons (p. 1718) provided the patient can swallow. If it is not dislodged, and is known to be an object without sharp edges, as a coin, for instance, it is best to induce it to go on into the stomach by drinking water, eating bread, mashed potatoes, or other soft food. Once in the stomach the patient, usually a child, should be made to eat all the mashed potatoes he can possibly hold, and a large dose of castor oil should follow. The potatoes form a mass around the foreign body, and the oil usually pushes this mass through the bowels without any trouble whatever. The stools or passages should be carefully watched to determine that the object passes, and if it does not, the doctor should be consulted without delay.

SERIOUS ACCIDENTS—FIRST AID

Bites and Stings of Poisonous Animals or Insects

"**Snake Bites.**—(Do not give alcohol or ammonia.) Poisonous snake bites must receive instant treatment. Fasten a bandage or handkerchief above the wound and twist it tight to prevent the flow of blood toward the body and heart. Cut the wounded flesh out so that it bleeds freely. If there is anyone with you get him to suck the wound immediately; thoroughly and repeatedly spitting out the blood and washing his mouth with water to eliminate all danger to him. A concentrated solution of potassium permanganate should then be poured into the wound or better injected around and above the wound, using the full charge held by an ordinary hypodermic syringe. When working in a snake country a small pocket case containing a sharp clean lancet, hypodermic syringe, and a bottle of potassium permanganate should always be carried. The tight bandage cutting off the flow of blood must be loosened within 10 min. of its application to permit some circulation, as a long-continued stoppage of blood causes gangrene. Even when the blood is allowed to circulate freely at intervals of 10 to 15 minutes the tight bandage should be removed entirely within a couple of hours. There is great danger in its prolonged use. Snake bites treated promptly in this way are rarely fatal, although they may make the victim very sick. The patient's vitality should be prompted by hot blankets, water bottles, etc.

"Wilson's "Topographic Surveying" states that in addition to this treatment the only sure cure, particularly for the more dangerous tropical snakes, is the hypodermic injection of Antivenene serum. The injection is made in the cellular tissue of the right or left side of the abdomen. Treatment should be immediate for best results, although it may be successful after as much as 3 or 4 hr. If there is time the skin should be carefully cleansed before using the syringe, the needle of which should be inserted deeply closely compressed with the fingers for a couple of minutes and then hastily withdrawn.

"Antivenene serum can be obtained from Les Establissements Poulenc Freres, 92 Rue Vieille-du-Temple, Paris. The serum will keep for years.

Dose 10 cc. (contents of one flask), or for large snakes, as the cobra, 20 cc. or two full doses at once.

"**Bite of Dog or Cat.**—This is usually a punctured wound; that is, the teeth enter without tearing the flesh, and the wound almost entirely closes, thereby preventing drainage and increasing the danger. Sucking the wound hard repeatedly and washing out the mouth with hot water may remove some of the poison. Squeezing is less effective. The wound should then be burned either with carbolic acid or a red-hot iron carried to the bottom, and the skin about the wound should be scrubbed with alcohol or other antiseptic. A drain of several strands of boiled sewing silk should be pushed into the bottom of the wound, and an antiseptic dressing or boiled cloth applied over the wound. The patient should then be taken to the nearest place where the Pasteur treatment to prevent hydrophobia or rabies can be secured. The hygienic laboratory of the U. S. Public Health Service in Washington, D. C., administers this treatment without cost.

"If the animal is known to be mad this treatment is imperative, and whether mad or not it is a very wise precaution and relieves the anxiety of the patient.

Bleeding (Hemorrhage)

"**Kinds of Blood-vessels.**—There are two kinds of blood-vessels. Those that carry the blood from the heart to all parts of the body are called arteries. The blood in them is bright red, and escapes in jets or spurts corresponding

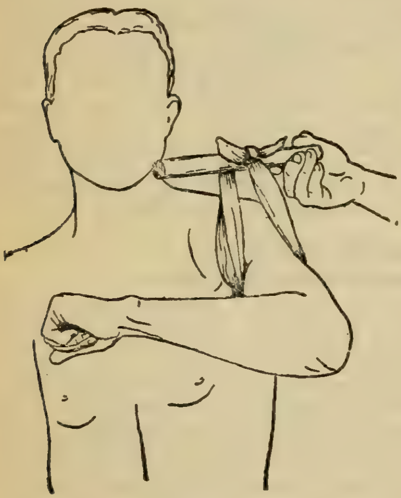

FIG. 3.

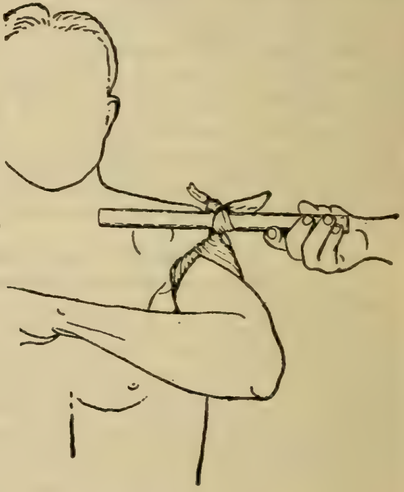

FIG. 4.

to each beat of the heart. Bleeding from these is more dangerous and more difficult to control, as a rule, than bleeding from the vessels that return the blood to the heart. Fortunately, however, the larger arteries in the limbs lie near the bones, and are consequently well protected in most parts by the mass of muscles covering them. The vessels that return the blood to the heart are called veins. They contain a darker blood than the arteries, and when cut the blood escapes in a steady stream, not in spurts. While the largest veins in the limbs are also near the bones, there are some of considerable size just under the skin.

"If we should desire to stop a stream of water flowing past a given point, we would naturally go upstream from that point and not downstream to adopt the necessary measures. When there is bleeding from an artery, the blood coming from the heart, the artery must be compressed at a place between the heart and the bleeding point. On the other hand, if a vein is bleeding, the blood flowing toward the heart pressure must be made on the vein at a place farther from the heart than the bleeding point.

"**Bleeding, General Treatment.**—Before beginning the treatment of any wound or any bleeding point, if there is time, the operator must carefully cleanse his hands and arms and also the wound and surrounding parts.

The instruments and silk ligature should be boiled, as described under wounds.

"In the aftertreatment of severe bleeding the patient should be kept perfectly quiet in mind and body, his head should be lowered by raising the foot end of his bed or bunk. Give him plenty of fresh air, keep his body warm, and give him hot drinks. After reaction the temperature of the body may rise a degree or two above normal, but if this should continue longer than two or, at most, three days, the dressing should be removed and the wound thoroughly irrigated, first with hot water, then with a solution of bichloride of mercury (1 to 5000) and dressed with aseptic gauze.

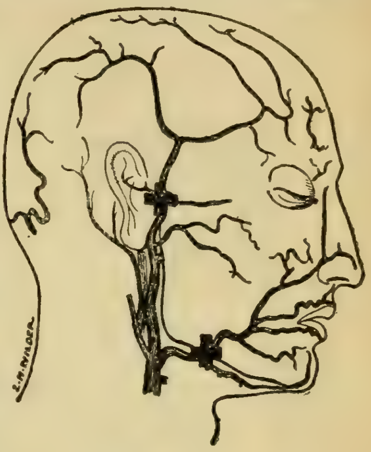

FIG. 5.

"**Bleeding from Arteries.**—There are certain places in the body where the arteries are not covered by much muscle, and can be easily compressed against bone. These places are shown in the illustrations. The bleeding should be controlled first by thumb pressure at the points indicated in the illustrations, and if the services of a doctor can be secured without delay, this will be all that is necesary until he arrives. If there is any doubt as to the exact place at which pressure should be made, a slight shifting of the thumb from one point to another should be made rapidly, and when the bleeding stops it indicates that the proper location has been reached and pressure should be continuous at this point. If a doctor is not within reach, the bleeding must, of oourse, be controlled by some other device. When the bleeding is from one of the limbs, and some distance from the body, a bandage or clean handkerchief should be wrapped around the limb

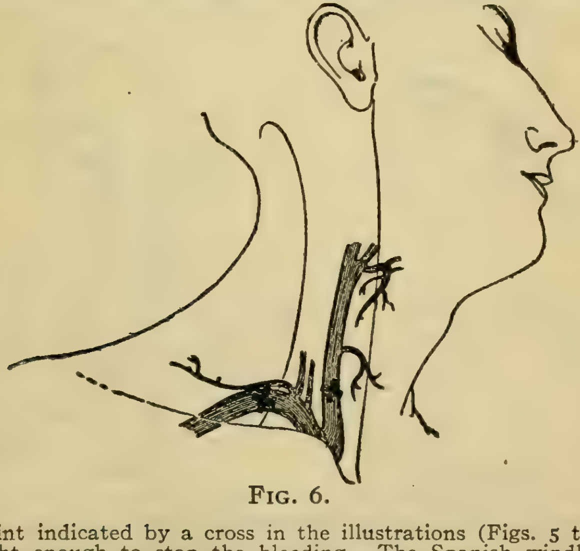

FIG. 6.

at the point indicated by a cross in the illustrations (Figs. 5 to 14) and drawn tight enough to stop the bleeding. The Spanish windlass (Figs. 3 and 4) is made by knotting a handkerchief around the limb loosely, passing a stick through the slack part, and taking up the slack by twisting the handkerchief. To prevent untwisting, the stick is then bound to the limb by one or two other bandages or handkerchiefs. A small round stone, a cork, or other similar object placed in the folds of the handkerchief and

lying directly over the vessel will assist. Only sufficient pressure should be made barely to stop the bleeding. The windlass must be loosened every 20 min. to give a chance for the blood to flow through the part, as there is great danger of gangrene (mortification) if the blood is entirely shut off for longer than this time.

FIG. 7.

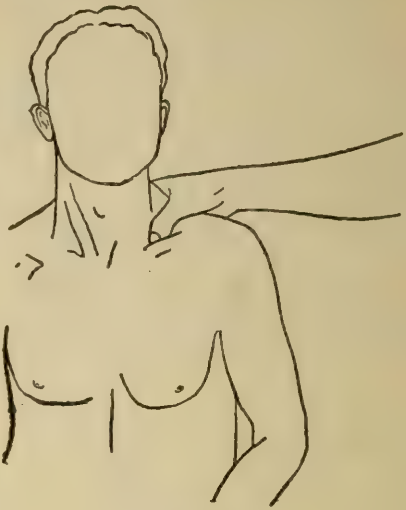

FIG. 8.

FIG. 9.

FIG. 10.

"The knot in the windlass should not be untied, and the stick should be left in position for immediate tightening if the blood again begins to flow freely. If the windlass is to be used for several hours, it is best to encircle the limb with a folded towel before applying it, as there is less danger of injuring the skin and soft parts. If the bleeding artery is in or near the body, where a windlass cannot be applied, thumb pressure must be kept up until the doctor arrives, one person relieving another. The second person's thumb

should gradually push the first person's thumb aside, and thus prevent a spurt of blood. In exceptional cases it may be necessary to place the thumb directly in the wound to control the bleeding, but, no matter how clean the thumb may be, this should only be resorted to in desperate cases, as there is

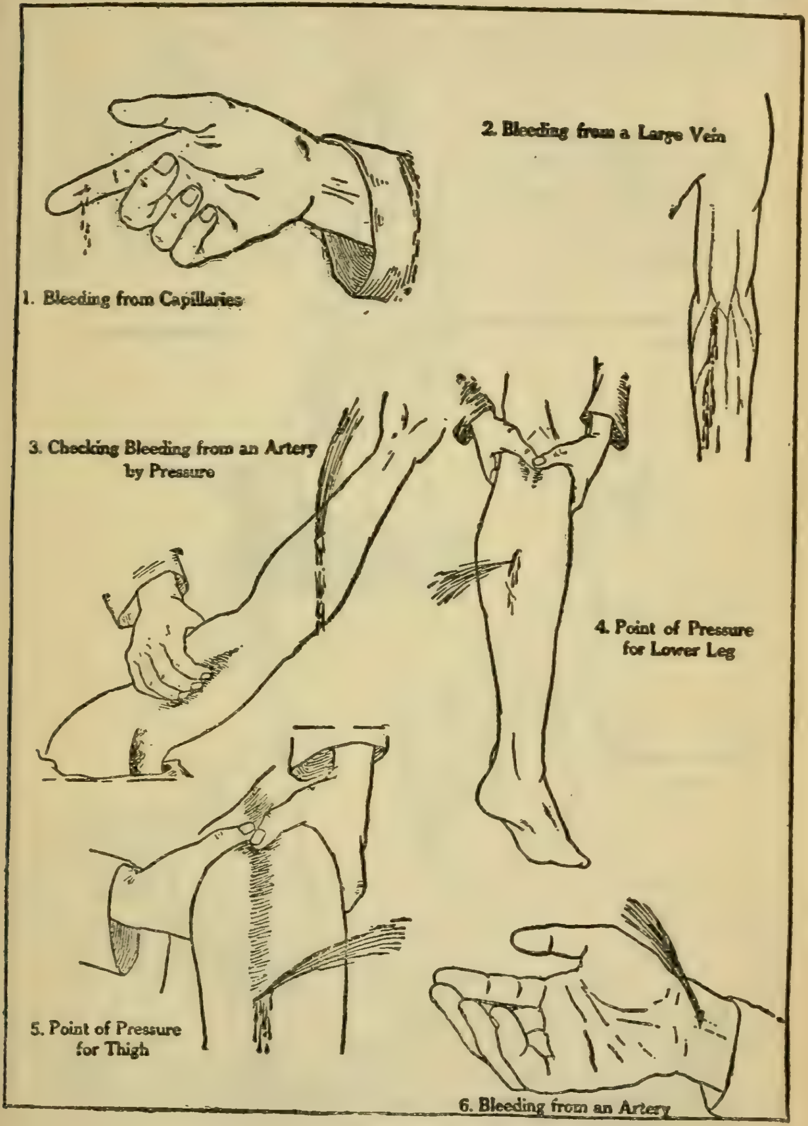

FIG. 11.

great danger of infecting the wound. Reference is made in this connection to the section of Antiseptics.

"In places where the services of a physician cannot be obtained, the wound should be stretched open, the blood-vessel located, seized, and drawn

gently forward with a pair of artery forceps, and the ends tied with heavy thread that has been boiled for 5 min. If artery forceps cannot be obtained, take a needle or a bent pin, pass it through a flame several times, hook onto the vessel, and draw it out; then tie it tightly with the thread described

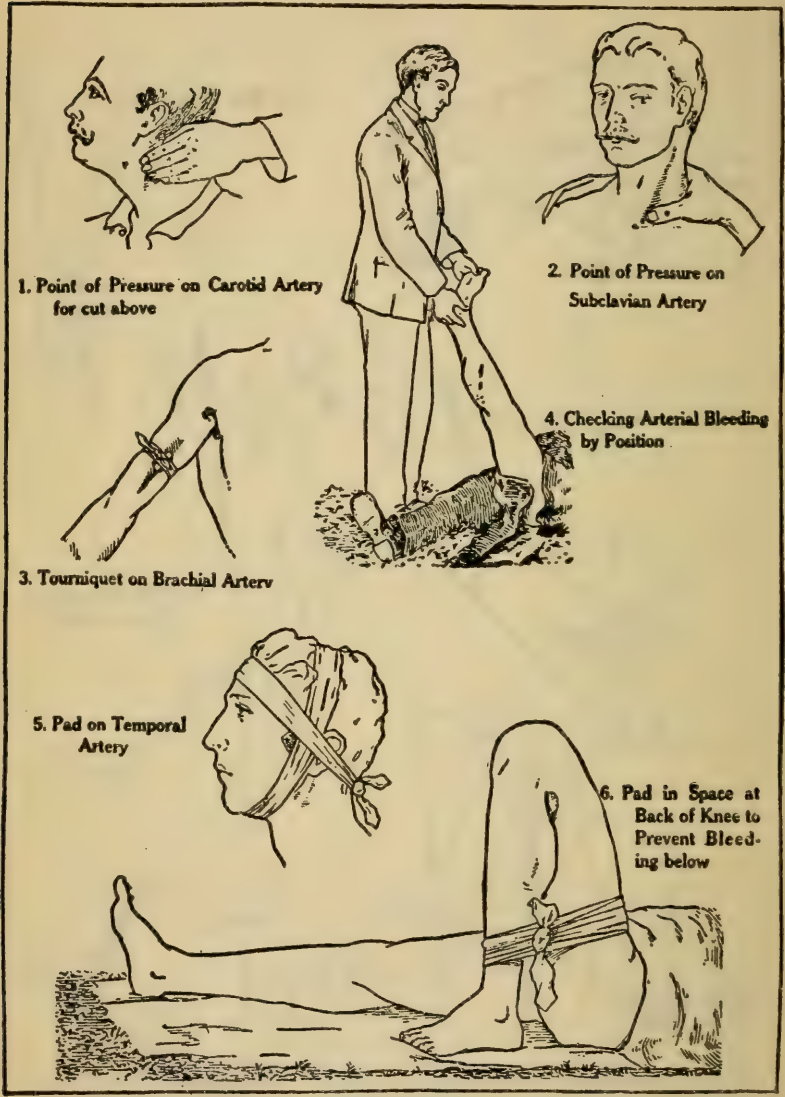

FIG. 12.

above. If a little flesh is tied in the knot with the artery, this will be of no consequence. After the artery has been securely tied the 'Spanish windlass' should be removed, or, if thumb pressure has been employed, this should be discontinued. The wound should then be closed as described under the heading Wounds.

"**Bleeding from Veins.**—The deep veins, as a rule, follow closely the course of the arteries. If thumb pressure on the far side (the side farthest from the heart) of the bleeding point fails to control the bleeding, a Spanish windlass should be applied on the far side. If the bleeding vein is near the surface, it may be possible in some cases to control it by a windlass with a stone or cork, the windlass not being drawn tight enough to shut off the deeper vessels. In some cases bleeding from veins is best controlled by pressure directly over the bleeding point, but the thumb should be covered by a clean cloth, such as a handerkerchief or towel. Elevation of the part and removal of all constricting bands, such as garters, will assist.

"Where there is simply an oozing of blood and it does not appear that any vessel of size has been severed the case can frequently be controlled by steady pressure of the bleeding surface. Sometimes cloths soaked in water as near the boiling point as can be borne and constantly changed will accomplish the result. If peroxide of hydrogen is at hand, it is one of the best-known agents to stop simple oozing.

"**Bleeding from Head and Face.**—Reference to Fig. 5 will show a point in front of the ear, compression upon which will control bleeding about the

FIG. 13.

FIG. 14.

temple. Another important point for pressure is shown where the artery crosses the edge of the lower jawbone. This controls bleeding in the parts supplied by this artery, as shown in the illustration. If the bleeding is severe and it is evident that a larger and deeper vessel is responsible, it is necessary to compress the large artery in the neck. If you will turn your own head well toward one shoulder, say the right, you will be able to feel on the left side a strong muscle standing out under the skin and extending from a point just back of the ear to the point where the left collar bone joins the breastbone. This is your guide to the deep artery. Pressure should be made deeply between the lower end of this muscle and the windpipe compressing the artery directly against the backbone (Figs. 6 and 7).

"**Bleeding from Shoulder.**—If the bleeding is in the neighborhood of the shoulder joint, the artery to be controlled is the one lying directly under the collar bone. Pressure is made downward, behind the collar bone, near the point where it joins the breastbone, the artery being compressed against the rib (Figs. 6 and 8).

"**Bleeding from Arm, Forearm, and Hand.**—If you place your left hand on your right arm between the shoulder and elbow and then bend the right elbow and straighten it out several times you will feel a muscle swell up in the arm and subside again. Extending along the inner edge of this muscle and close to the bone a large artery can be felt beating (Figs. 9

and 10). This is the one to compress when bleeding is from a point in the arm or forearm. If the forearm, the best place to compress this last-mentioned artery is just above the elbow; and is also the best point if there is severe bleeding in the hand.

"**Bleeding from Thigh or Leg.**—In the groin, halfway between the hip bone and the middle line of the body, the main artery supplying the thigh and leg can be pressed against the bone (Fig. 13). If the bleeding is from the back of the knee, the leg, or foot, the best place to apply pressure is just above the knee at the back of the thigh (Fig. 14).

"**Bleeding from Lungs and Stomach.**—If the blood is from the lungs, it is generally coughed up and has the bright-red appearance of ordinary blood. If from the stomach, the acid of the stomach juice changes the blood until it has more the appearance of coffee grounds. If, however, the bleeding is severe, the vomited blood may be bright red, as the acid of the stomach may not have had time to act upon it. Sometimes blood brought into the throat from the lungs is swallowed by the patient and later vomited in its changed condition.

"In the treatment of either of these conditions, it is best to keep the patient very quiet in bed, let him suck small pieces of ice in limited quantity, and apply cracked ice in some waterproof covering over the chest or pit of the stomach, as the case may be. Cheerfulness and an encouraging attitude on the part of the attendants are necessary.

"**Bleeding from the Nose.**—If bleeding of the nose occurs in a full-blooded person, especially if such person is subject to dizziness, we should not be in too much of a hurry to stop it. But if the bleeding is the result of injury or if it occurs in a person suffering from disease of the heart or lungs or from the effects of malarial fever, scurvy, or any disease of the general system, effort should be made to stop it. Nosebleed from a blow, in a healthy individual, usually stops in a short time without any particular treatment. If it does not stop, place a piece of paper folded to the thickness of a quarter of an inch well up between the upper lip and gum, and compress the lip tightly against it. The main blood-vessels supplying the nose pass upward from the corners of the mouth to the sides of the nose, and this paper tends to compress the vessels and shut off the blood supply. The patient should lie on his back with his head on a pillow. If ice is obtainable, it should be cracked into small pieces, wrapped in a thin cloth, and placed over the nose, a sufficient quantity being used to cover the whole surface. Cold applied to the back of the neck will also do good in some cases. If the bleeding is obstinate, a strip of gauze or soft cloth can be pushed gently into the nostrils, the ends being allowed to hang out.

"**Bleeding from the Urinary Canal.**—This is usually caused by falling astride of a hard object. The bleeding may be profuse, but is usually controlled by pressure with a folded towel. If the bleeding is severe, a stick with a cross-piece at one end should be placed at the foot of the bed, the cross-piece pressing against the towel in the crotch. After the bleeding ceases, the patient should be kept quiet and cold applications should be used.

Burns and Scalds

"**Burns.**—Burns or scalds are serious and dangerous to life in proportion to the extent and depth of the injury. A burn covering a large area and producing mere reddening and swelling of the skin is as serious as a burn one-half the size in which the skin is destroyed. The danger is from shock, from fever following reaction, from hemorrhage following sloughing, and from congestion and inflammation of internal organs. Burns of slight extent or moderate degree are not so dangerous, and most of the cases commonly met with will recover. But all cases require careful treatment.

"**Treatment.**—The indications for treatment in these two conditions are virtually the same if the damage is superficial; and this is usually the case, the injuries being only skin deep. Blisters should be pricked with a needle that has been passed through a flame several times. This allows the water to escape from the blisters, but the skin raised by the blisters should not be removed. If the burning agent is pitch or tar, and adheres to the skin, it should not be removed; it will come away later with the blistered skin. Any bland oil, such as sweet oil, linseed oil, or Vaseline, forms a soothing application. Ordinary baking soda or a saturated solution of soda in water can be used. The old 'Carron' oil made of linseed oil and lime water, half and half, is excellent, but has an unpleasant odor. If lime water is not at hand, it may be obtained as follows: Quicklime is first slaked by adding

to it gradually about 30 times its weight of water. Agitate during ½ hr., allow the lime to settle, and reject the liquid. Add to the residue of lime about 300 times its weight of water, agitate frequently during the next 24 hr., and allow the lime to settle. The clear water standing above the undissolved lime is lime water.

"The parts burned or the entire body, except the head, may be kept immersed in tepid or warm water for days. Cream or white of eggs may be used, but they are apt to become offensive after 24 hr. Kerosene is an old household remedy. One teaspoonful of table salt in a pint of water makes a solution that can be employed. Keep the patient quiet and his bowels active. Pain or restlessness may be relieved by laudanum, 20 drops repeated in 2 hr.

"If the eye is red from contact with the flames or hot fluid, sweet oil is perhaps the best household remedy to drop in. A bandage lightly applied over the eyes to keep out the light will be soothing.

"If the skin or the eye is burned with acid, a solution of baking soda should be used first. If the burning agent is an alkali, such as hartshorn or lye, weak vinegar or lemon juice should be used. Sweet oil should be dropped in the eye after such treatment.

"If the patient has breathed the flame or steam the condition is apt to be a serious one, even though it does not appear so at once. Complete rest and quiet, an ice bag to the chest, the giving of milk and cream, half and half, if swallowing is possible, should be employed. Artificial respiration, as described elsewhere, may be applicable in some cases.

"Speaking generally of burns and scalds, a superficial burn covering a large part of the skin may be more dangerous than a deep burn confined to a small part, for reasons which it is unnecessary to discuss in a book of this kind. No burn or scald should therefore be treated as a trivial matter. Where solutions are used the bandages should be soaked in the same before applying and the solution should be poured over the bandaged part of frequent intervals.

"Paraffin mixtures have been recently used extensively for the treatment of burns. The mixture is melted and then sprayed upon the burned surface. It is then covered with a layer of gauze and more of the mixture is sprayed on. Instead of spraying, the mixture may be painted on the surface with a sterile brush. The mixture becomes hard when it cools, forming a protective coating for the burn. The paraffin should be removed once a day, the wound washed with a weak antiseptic solution, dried with pellets of gauze or cotton, after which another coat of the paraffin mixture is applied. Melted wax may be employed instead of paraffin. In either case a coating of liquid petroleum or kerosene should be applied to the wound before the wax or paraffin is used.

"The scars resulting from burns and scalds always contract, and in severe cases terrible deformities are produced. These may be prevented to some extent by active and passive motion and by splints.

Effects of Cold—Frostbite

"**Frostbite.**—Severe cold depresses the action of the heart, suspends the circulation. These effects are first noticed in the ears, nose, fingers, and toes. Numbness and tingling are the first symptoms, then loss of sensation. If not too long exposed, the circulation may be restored by proper treatment. But if the exposure is long continued or if the cold is very intense the parts are hopelessly frozen and gangrene will be the result. The parts may look all right for a few days after reaction and then become discolored, bluish, and finally black. Another effect of extreme cold is an overpowering sense of drowsiness, but to lie down and go to sleep under such circumstances is almost certain death.

"**Treatment of Frostbites.**—1. Do not bring the patient to the fire until the circulation is restored in the frozen part.

"2. If snow be on the ground or accessible, take a woolen cloth in the hand, place a handful of snow upon it, and gently rub the frozen part until the natural color is restored. In case snow is not at hand bathe the part gently with a woolen cloth in the coldest fresh water obtainable, ice water if practicable.

"3. In case the frostbite is old and the skin has turned black or begun to scale off do not attempt to restore its vitality by friction, but use the treatment for burns described on page 1708.

"4. In the case of a person apparently dead from exposure to cold, friction should be applied to the body and the lower extremities and artificial respira-

tion practised as in case of the apparently drowned. As soon as the circulation appears to be restored administer $\frac{1}{40}$ gr. strychnine sulphate. Even if no signs of life appear friction should be kept up for a long period, as instances are on record of recovery after several hours of suspended animation.

Antisepsis, Antiseptics, and the Dressing of Wounds

"We are surrounded at all times by very minute organisms capable of producing various diseases or complications. They are sometimes called 'germs,' and more vulgarly called 'bugs.' The latter name is incorrect, as the germs belong to the vegetable and not the animal kingdom. In first-aid work the germs that particularly interest us are those that get into wounds and infect them, causing pus or 'matter' and sometimes blood poison.

"**Definitions.**—When these complications arise the process is known as 'sepsis.' 'Antisepsis,' therefore, refers to the question of removing or killing the germs, and 'antiseptics' are the medicines or other agents used in accomplishing these purposes. This explanation is made for the reason that it is necessary to use the terms 'antisepsis' and 'antiseptics' in this chapter, there being no common names quite so expressive. There is, another term, 'asepsis,' used by doctors, which refers to the condition where all germs have been removed or killed, but this is a condition that does not often obtain in first-aid work administered by a layman, and therefore will not be further discussed. We frequently hear a person say that he has good blood because when he cuts himself the wound heals quickly. This is apt to give him a false sense of security and cause him to neglect the precautions that should be taken. Some of the worst cases of 'sepsis' and blood poison occur in strong healthy men who have had no previous trouble in the healing of wounds. Germs are always present on the skin and can be demonstrated by laboratory methods. They can only be seen by a microscope of high power. A patient may have taken a hot soap bath before being injured, but his skin is not surgically clean, and antiseptics are therefore employed to destroy the germs that remain.

"**The Dresser's Hands.**—The one who is to make the dressing should see that his own hands are surgically clean before he attempts to clean or 'sterilize' the wound; otherwise he is apt to transfer germs from his hands to the wounds or to the dressings. The hands should be scrubbed with a nailbrush, hot water, and soap. Then the finger nails should be cleansed and the hands scrubbed again. A good way to clean the finger nails is to rake them across a cake of soap, filling the space under each nail with the soap. As this is removed with a pocketknife the dirt comes away with it. Then after the second scrubbing the hands should be soaked and rubbed in some antiseptic solution and not dried. The skin about the wound should now be scrubbed with the nailbrush and soap; and if it is a hairy part, the hair should be shaved for some distance on all sides of the wound before the scrubbing. The wound and the parts about it should then be thoroughly cleansed with the antiseptic solution; and a cloth, preferably one that has been boiled, soaked in the antiseptic solution, laid over the wound, and bound there with a bandage.

"**Alcohol.**—The antiseptic that is most apt to be at hand or most easily obtained is alcohol. It should be diluted with water, making a mixture of 1 part water and 3 parts alcohol. It creates a burning sensation when applied to a wound, but this is a small matter if it prevents infection in the wound. Where alcohol cannot be obtained, whisky or brandy, which contains about 50% of alcohol, may be obtainable. Some experiments have recently been made in the San Francisco Federal Laboratory by officers of the U. S. Public Health Service showing that whisky and brandy are very good antiseptics.

"**Iodine.**—Tincture of iodine, usually known by the layman as simply 'iodine,' is one of the best antiseptics known at the present time. Its power is far greater if applied to a dry surface than to a wet surface. The burning sensation produced in the wound does not last long. A dry sterile dressing over it is preferable to a wet dressing, as the wet dressing lessens its power and is apt to blister the skin. Too much iodine may also blister, and it should therefore be diluted with an equal part of alcohol.

"**Bichloride of Mercury.**—An antiseptic much used in hospitals is bichloride of mercury or corrosive sublimate. It is not apt to be on hand in the ordinary household or camp, but is mentioned as one of the agents to be kept in the first-aid chest. It can be purchased in tablet form, 7.3 grains each and each tablet added to a pint of water makes a solution of 1 part bichloride to 1000 part of water. This strength that is safest for the layman to use is 1

part of bichloride of mercury to 5000 parts of water. This is an excellent antiseptic. It is a deadly poison, however, if taken internally, and should therefore be handled with care.

"**Peroxide of Hydrogen.**—Peroxide of hydrogen has become a favorite and popular antiseptic. Its power in this regard is weak, but it is a cleansing agent and can be employed as a dressing in the absence of anything better. It tends also to stop oozing of blood in a wound where no large vessels are cut.

"**Carbolic Acid.**—The pure carbolic acid should be obtained if possible, and as a dressing for wounds should be made into a solution of 1 part of carbolic acid to 100 parts of hot water.

"**Compound Cresol Solution.**—This is a very serviceable antiseptic solution, as it readily dissolves in cold water and is as powerful as carbolic acid solutions of the same strength. It may be employed in 1% solutions for any purposes for which an antiseptic solution is required. It is especially good for sterilizing instruments, as it does not injure them.

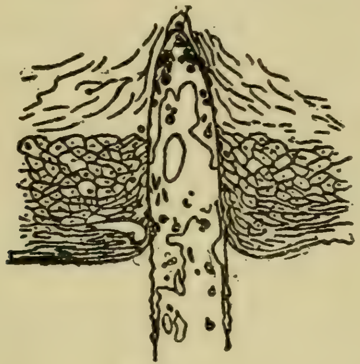

FIG. 15.

"**Sterile Dressings.**—There can be purchased for the first-aid chest various kinds of sterile dressings; that is, dressings that have had all germs killed by exposure to heat. Sterile gauze comes packed in a box in the form of a roll, and it unrolls as pieces are drawn out and cut off. From a theoretical standpoint the gauze is no longer sterile after the package has once been opened; but for practical first-aid work it answers the purpose if each piece cut off is carefully unfolded with clean hands and the inside of the piece applied next to the wound. It is advisable to buy small packages, so that a new one will be opened from time to time.

"**How to Sterilize Dressings.**—The one most efficient and always available method of sterilizing dressings is by boiling for 10 min. in plain water, which, from a practical standpoint, kills all germs that can infect a wound. If a dry dressing is desirable, it can be placed in a pan in a hot oven for 15 or 20 min. and removed just as it is beginning to be scorched. If several layers of a sterile dressing are applied directly over a wound and lapped around it at all sides, it is not absolutely necessary that the additional dressing material placed over this be sterile, although it is desirable.

"**Sterilizing Instruments, Etc.**—If scissors, knitting needles, ordinary needles, or other metal instruments or implements are necessary in dressing a wound, they should be boiled in water for 10 min., or can be passed through a flame several times, or some alcohol can be poured on the instrument and then set on fire with a match. Actual fire is apt to remove the temper from the instrument much more easily than boiling, for which reason boiling is preferable.

"**Treatment of Wounds.**—Doctors divide wounds into several classes, namely, incised, lacerated, contused, punctured, poisoned, gunshot, and infected. The nature of the first three is sufficiently clear from their names and from a first-aid standpoint may be considered together. The first thing to do is to control severe bleeding by pressure on the wound or upon a distant part of the blood-vessel, as explained in the data on 'Bleeding.' Then, after the dresser has disinfected his own hands, the wound should be thoroughly

cleansed and disinfected; these matters will be explained in 'Antiseptics.' Iodine, if at hand, is the best agent to use. If the wound is on a hairy part, as the scalp, the hair should be shaved for a distance of several inches from the wound. An antiseptic dressing should then be applied, or in the absence of any such agent one may use a clean cloth boiled for 10 min. in clear water or in water to which table salt has been added in the proportion of 1 teaspoonful to the pint. This dressing is retained by a bandage and should not be disturbed for any reason except bleeding if the doctor can be reached within 48 hr.

"If it is impossible to secure the services of a doctor for several days and the wound gapes to such an extent that it cannot be readily closed by bandaging, or is in a part where a scar will mean disfigurement, the layman may attempt to close the wound by stitching, and this can be done by using an ordinary sewing needle with silk or linen thread, both boiled for 10 min., the needle being pushed through the flesh by means of a thimble, also boiled. The stitches should pierce the skin about an eighth or quarter of an inch from the edge of the wound and come out of the fleshy part of the wound about the same distance from the skin. They should be placed about half an inch apart, and each one should be tied and cut off. The stitches should only be drawn tight enough barely to close the wound, because the swelling may make them too tight. No wound should be closed by a layman without leaving drainage; that is, something that will lead off the bloody water that oozes from a wound.

"A piece of boiled sewing silk or linen folded back and forth and then twisted until it makes a skein one-eighth of an inch thick should be laid in the bottom of the wound and allowed to hang out at the lower end for a distance of an inch. This drains by capillary attraction, and there is far less danger of blood poison than if the wound were closed tightly. This drain should be removed after 24 hr. by simply drawing it out without disturbing the stitches. The stitches themselves should be left in place from three to six days, depending principally upon the depth of the wound and its tendency to gape. The stitching of a wound should only be attempted by a layman when a doctor cannot be reached within 48 hr.

"The closure of a wound by sticking plaster is a questionable expedient, because it seals the wound, prevents drainage, and blood poison may follow. If the wound is not large, a strip of boiled cloth may be laid directly over it and the wound then drawn together by strips of sticking plaster applied outside the cloth.

"Whether the wound is closed by stitches or not, the layman should apply an antiseptic dressing, if such is available, and if not, a boiled cloth, as described above, can be used.

"A badly contused or bruised wound should not be stitched by a layman. In a lacerated wound it may be necessary to trim off with boiled scissors a few ragged edges of skin before stitching.

"If a wound has penetrated the belly and the bowel is protruding, it is best not to attempt to push it back if the doctor can be reached within a few hours. It should be gently washed with the salt solution, described at top of page and kept covered with towels frequently wet with the same solution. If a doctor cannot be reached within a few hours, and the person in charge of the patient after a careful examination is sure that the bowel has not been opened or otherwise seriously injured, he should, after carefully washing the bowel with the salt solution mentioned above, return it to the belly. If the bowel is allowed to remain for too great a time outside of the belly, its circulation may be cut off by the pressure of the belly walls and gangrene result. If the bowel has been opened or severely bruised, it should not be returned, as there is danger of forcing fecal matter out of the bowel into the belly cavity, which would cause a dangerous inflammation. If the bowel is not protruding from the wound, simply treat as an ordinary wound.

"**Punctured Wounds.**—A punctured wound is one made by a piercing agent, such as a nail, tack, knife, or needle. Such a wound is dangerous, because it almost completely closes and does not drain. If germs are introduced at the time of the accident, they cannot escape. A wound of this kind, except of the chest or belly, should be disinfected or burned, and the best agent is pure carbolic acid. In the absence of suitable instruments a knitting needle or other thin blunt implement should be dipped into the carbolic acid and then inserted to the full depth of the wound. This should be repeated several times. The first application causes a burning sensation, but the acid itself soon deadens the part, and the subsequent

applications are less painful. If the knitting needle is then dipped in alcohol or whisky and inserted once or twice and a little is applied to the skin about the wound, it will stop the burning action of the carbolic acid. In the absence of the carbolic acid the alcohol or whisky can be used alone, but are far less efficient. After this treatment an antiseptic dressing or, a boiled cloth should be applied to the wound. The frequency with which lockjaw follows punctured wounds, particularly nail wounds, makes it imperative that the doctor be consulted promptly and that the wound be not regarded as trivial because it is small in size. An injection of serum (tetanus antitoxin) will prevent lockjaw.

"**Poisoned Wounds.**—The principal poisoned wounds met with are those due to bites of animals or bites and stings of insects, and these have been considered under a separate heading (see p. 1701).

"**Gunshot Wounds.**—A gunshot wound is similar to a punctured wound in that it is small and almost completely closed. If the ball has passed entirely through a part, as the leg, and has not struck an important vessel or broken a bone, the wound is apt to cause less trouble than one in which the ball remains in the flesh. If a portion of clothing is found in the mouth of the wound, it should be removed. The part should be well cleansed with soap and hot water and an antiseptic dressing or a boiled cloth applied. Further than this it is not best for the layman to attempt anything, particularly probing for the bullets. If a bone has been broken by the ball, the case should be treated as described under 'Compound Fracture.'

"**Infected Wounds.**—A wound should never be permitted to become infected, but it is not always possible to prevent it, as germs may be introduced at the time of the injury by the weapon causing the injury or on pieces of cloth or in dirt carried in with it. Badly contused wounds are also liable to become infected as the devitalized tissue is unable to resist the attack of harmful bacteria. Continuous or frequent irrigation with an antiseptic solution has been found to be the best method of thoroughly cleansing wounds of this kind and to keep them free from bacteria. A very weak bichloride solution (1 to 15,000) may be used for this purpose, or, even sterile water containing one teaspoonful of salt to the quart may be employed if nothing else is available. The Dakin-Carrel solution, is, however, the best for this purpose. Tablets for the preparation of this solution, known under the trade name of Chlorazene tablets, can now be obtained in the drug stores. In order to be effective, the solution should be introduced to the bottom of the wound. A special apparatus is employed for this purpose. Gauze is packed around rubber tubes after they are placed in the wound. Only enough solution to keep the dressing damp should be allowed to flow into the tubes. A modification of this solution has recently been made in which oil is used instead of water. This makes it unnecessary to be continually wetting the gauze as the oil keeps the wound moist for a longer period and the wound need therefore be dressed but once a day.

Resuscitation from Apparent Drowning

"In the act of breathing, the oxygen from the air is absorbed from the lungs into the blood vessels and purifies the blood; at the same time the impure matters picked up by the blood in circulating through the body are filtered out by the lungs and pass off to the atmosphere with the breath. When a person is under water he can hold his breath for a short time, keeping out the water; then he swallows some water into the stomach, and as his strength fails water enters the lungs. The water in the stomach does no particular harm; but that in the lungs is of vital importance because it stops breathing, causes poisoning of the system from lack of purification of the blood, and if allowed to remain for any length of time produces stoppage of the heart and death.

"The indications, therefore, in one apparently drowned are to remove the water from the lungs, to make the patient breathe, and to stimulate the weak heart.

"The old method of rolling a patient over a barrel to remove the water from the lungs is not considered efficient by those who have had most experience. Inverting the patient by grasping his feet and holding him head down for a few moments, at the same time making pressure on his belly inward and toward the chest, may remove part of the water. The chest is separated from the belly by a partition consisting of a thin flat muscle, and pressure inward and upward on the belly forces this partition up against the lungs and may mechanically squeeze some water out of the

tubes in the lungs. Time should not be wasted in prolonged efforts to remove the water, as it is important to proceed as quickly as possible with artificial breathing, which will not only squeeze the water out of the lungs but will renew respiration and revive the patient.

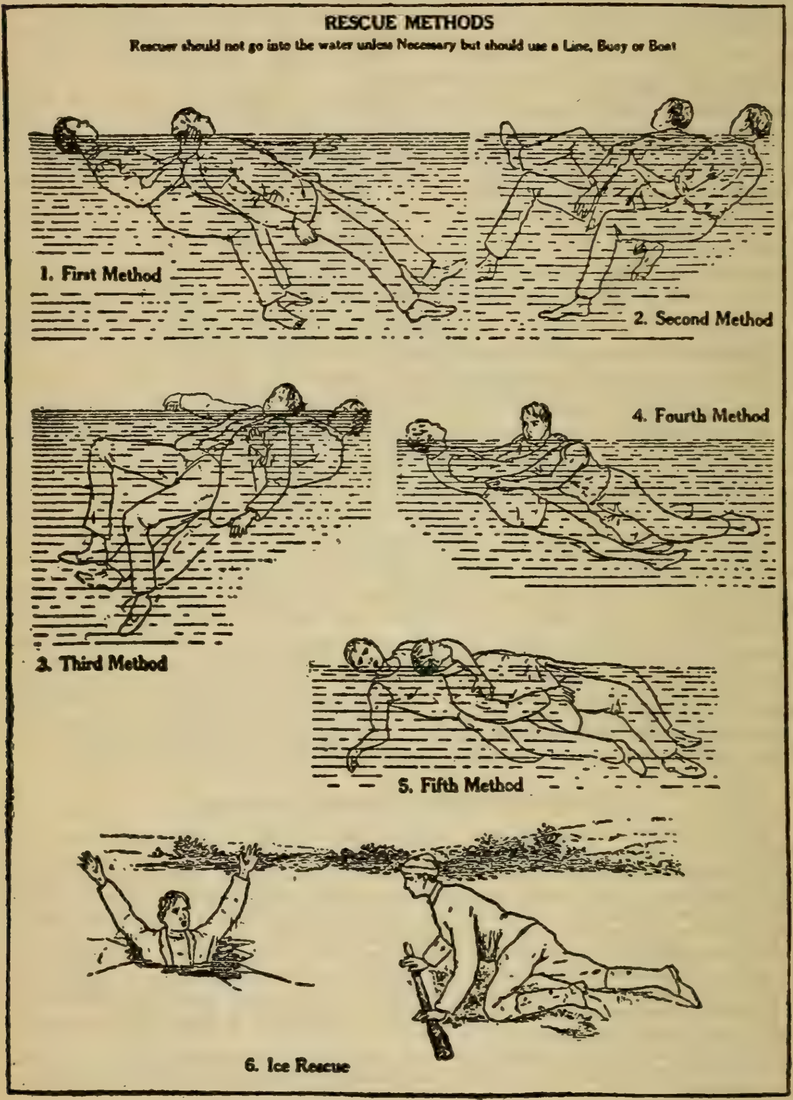

FIG. 16.

"There are several methods that have been suggested and used for inducing artificial breathing, but to save delay in selecting one the layman should have explained to him in a book of this kind one method only, and that one the method that has been accepted as the best, namely, the Schafer method (see Fig. 17).

"Schafer's description of this method, as quoted by Crile, is as follows, except that the technical words and expressions have been eliminated and ordinary ones that will be understood by a layman substituted:

"The subject, whether a drowned person or not, is allowed to lie prone, *i.e.*, face downward, no preliminary manipulation of the tongue being

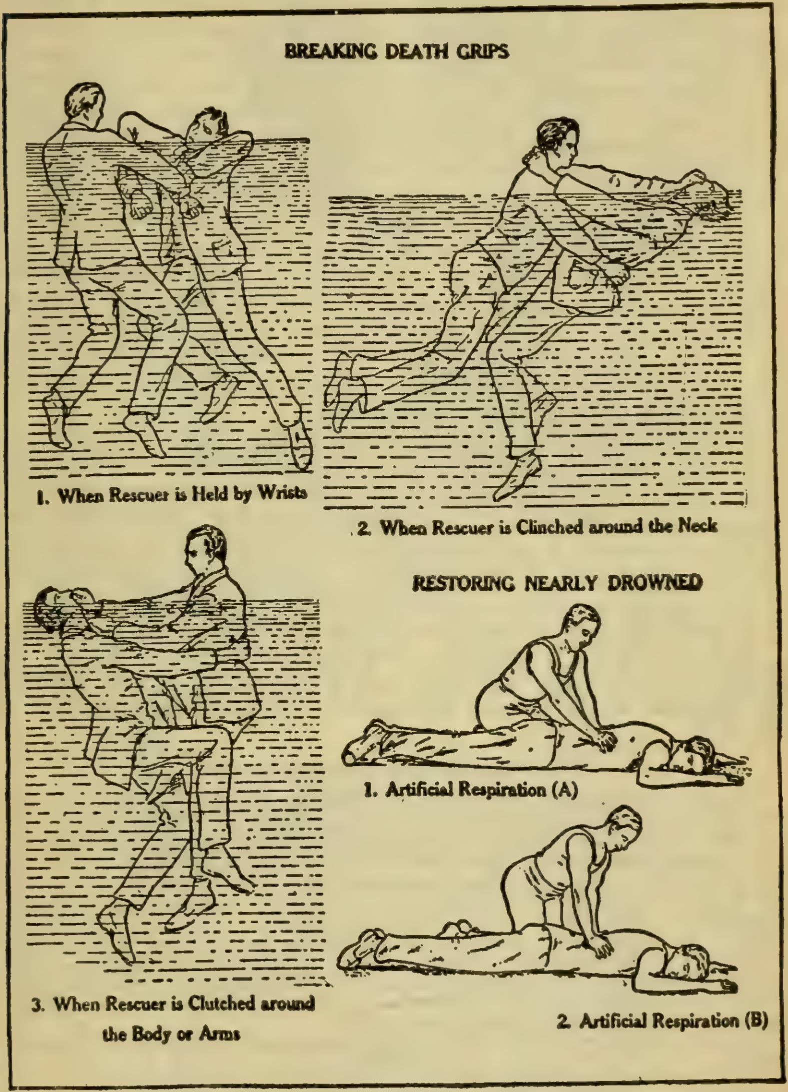

FIG. 17.

required. The operator kneels or squats either across or on one side of the subject, facing the head, and places his hands close together flat upon the back of the subject over the loins, the fingers extending over the lowest ribs. By now leaning forward upon the hands, keeping the elbows extended, the weight of the operator's body is brought to bear upon the sub-

ject, and this not only compresses the lower part of the chest but also the belly upon the ground, the pressure being fairly equally distributed. The result of this is that not only is the chest diminished in extent from before back, but, owing to the pressure which is communicated to the belly, the belly contents are compressed and tend to force the muscle partition between the chest and belly up, so that the chest is diminished in capacity from above down. This is no doubt the reason why the pressure method when applied with the subject lying on his belly is more effective than when applied, as by Howard, with the subject lying on his back. The pressure is applied not violently but gradually during about 3 sec., and is then released by the operator swinging his body back, but without removing his hands. The elasticity of the chest and belly causes these to resume their original dimensions and air passes in through the windpipe. After 2 sec. the process is again commenced, and is continued in the same way, the operator swinging his body forward and backward once every 5 sec., or about 12 times a minute, without any violent effort and with the least possible exertion. This last condition, *viz.*, the absence of muscular exertion, other than that involved in swinging forward and backward, renders it possible to continue the process without fatigue for an indefinite time. It can further be carried out unaided by a woman almost as well as a man, by children upon children; it hardly requires to be taught, a simple demonstration sufficiently teaches it to a large audience. Its advantages in drowning cases over any other method which involves the position on the back are sufficiently obvious, for with it there is no risk of obstruction by water or slime or the contents of the stomach, which can not accumulate in the throat, but must come away by the mouth, and the tongue, in place of falling back, as in the position on the back, falls forward and is unable to produce obstruction.

"Crile says in regard to this method: 'Schafer's method should be used in all cases in the absence of medical assistance or outside of a hospital, and even in a hospital in the absence of immediate surgical aid.' He further says: 'Simple artificial respiration is the only hope in drowning and other accidents occurring when professional help is not at hand.' When the patient is able to swallow, a small cup of black coffee, or hot milk may be given, and repeated a few times at intervals of an hour. If he does not swallow well, and an ordinary syringe is available, the coffee may be injected into the bowel and left there, but the effect is slower.

"It is scarcely necessary to state that the patient should be removed to a warm place, the wet clothing removed, and the lower parts of the body covered and artificially warmed. Pending the arrival of the doctor the patient should be closely watched, and if signs of collapse appear, renewed efforts should be made. Prolonged and systematic rubbing of the skin and kneading of the muscles will assist in promoting the circulation of the blood.

Resuscitation from Electrical Shock[1]

"An accidental electric shock usually does not kill at once, but may only stun the victim and for a while stop his breathing.

"The shock is not likely to be immediately fatal because (*a*) The conductors may make only a brief and imperfect contact with the body. (*b*) The skin, unless it is wet, offers high resistance to the current.

"Hope of restoring the victim lies in prompt and continued use of artificial respiration. The reasons for this statement are: (*a*) The fact continuously depends on an exchange of air, as shown by the fact that we must breathe in and out about 18 times a minute. (*b*) If the body is not thus repeatedly supplied with air, suffocation occurs. (*c*) Persons whose breathing has been stopped by electric shock have been restored after artificial respiration has been continued for approximately 2 hr.

"INSTRUCTIONS.—Follow these instructions even if the victim appears dead.

"I. Break the circuit immediately.

"1. With a single quick motion separate the victim from the live conductor. In so doing avoid receiving a shock yourself. Many have, by their carelessness, received injury in trying to disconnect victims of shock from live conductors.

"Observe the following precautions: (*a*) Use a dry coat, a dry rope, a dry stick or board, or any other dry non-conductor to move either the victim or

"[1] Taken from "Rules for Resuscitation from Electric Shock." Issued by the National Electric Light Association.

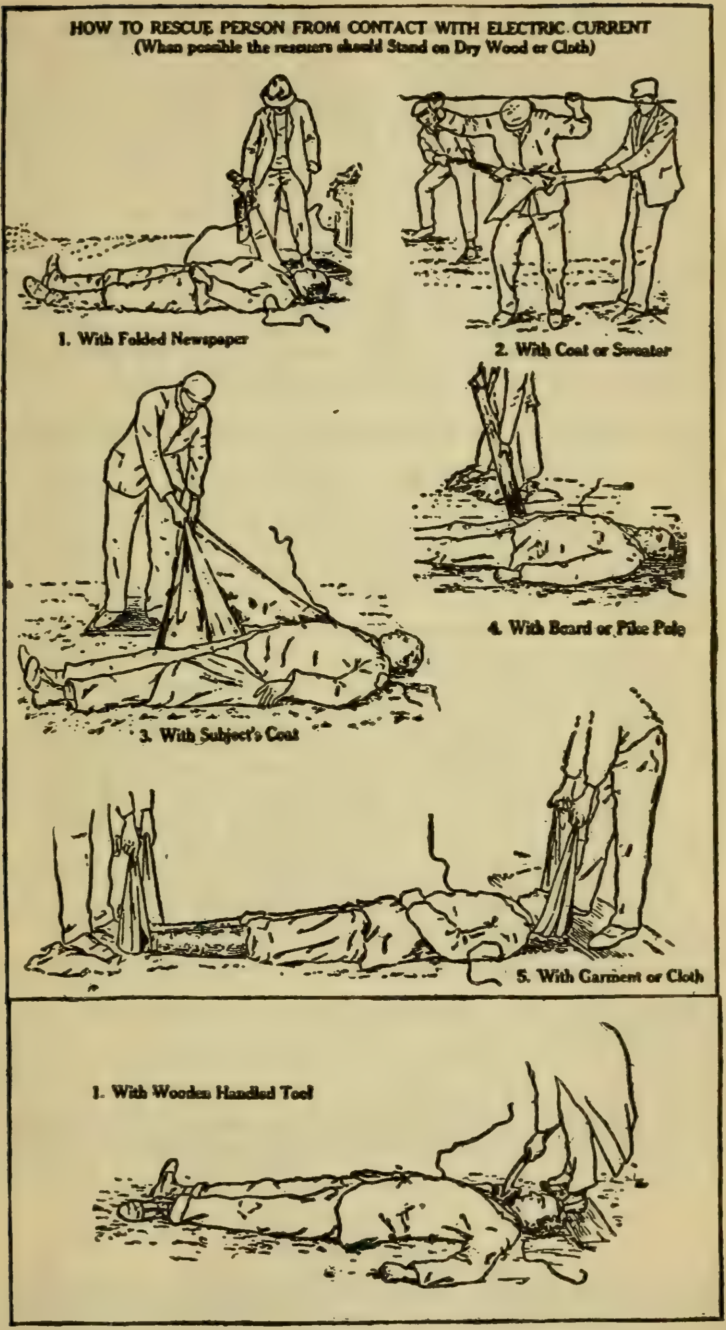
HOW TO RESCUE PERSON FROM CONTACT WITH ELECTRIC CURRENT
(When possible the rescuers should Stand on Dry Wood or Cloth)
1. With Folded Newspaper
2. With Coat or Sweater
3. With Subject's Coat
4. With Board or Pike Pole
5. With Garment or Cloth
1. With Wooden Handled Tool

Fig. 18.

the wire, so as to break the electrical contact. Beware of using metal or any moist material. The victim's loose clothing, if dry, may be used to pull him away; do not touch the soles or heels of his shoes while he remains in contact, the nails are dangerous. (*b*) If the body must be touched by your hands, be sure to cover them with rubber gloves, mackintosh, rubber sheeting, or dry cloth; or stand on a dry board or some other dry insulating surface. If possible, use only one hand. If the victim is conducting the current to ground, and is convulsively clutching the live conductor, it may be easier to shut off the current by lifting him than by leaving him on the ground and trying to break his grasp.

"2. Open the nearest switch, if that is the quickest way to break the circuit.

"3. If necessary to cut a live wire use an ax or a hatchet with a dry wooden handle, or properly insulated pliers.

"II. Attend instantly to the victim's breathing. Use the Schafer method of artificial respiration as described under treatment of the apparently drowned (p. 1713). Burns of the skin should be treated as described for ordinary burns. Warmth to the body, gentle rubbing, and later hot water, milk, or coffee if the subject can swallow, are indicated, but do not give any liquids whatever by mouth until the subject is fully conscious.

DIRECTIONS TO BE FOLLOWED IN CASE OF POISONING

"Send for the doctor immediately, if practicable, and if the nature of the poison is known, have the messenger inform the doctor so that he may come prepared. If the poison is unknown, but the bottle from which it was taken is found, save the bottle, as it may help in case of legal investigation. If the poison has been taken with suicidal intent and the patient survives, the same caution is applicable that was mentioned under Drowning, Gas Poisoning, etc. Warmth to the body, light stimulation, and encouragement are indicated.

"In treating cases of poisoning first give an antidote, if one is available; second, promote early and repeated vomiting to remove the bulk of the poison; third, give something that will help envelope the poison left in the stomach and prevent its further absorption into the system; fourth, remedy the damage that has been done, so far as this is possible.

"The following 'general antidote,' which should be prepared as needed, should be given when poisoning by any of the poisons mentioned in this book occurs or if the poison is unknown: magnesia, 2 teaspoonfuls; charcoal, 2 teaspoonfuls; tannic acid, 1 teaspoonful. These dry powders should be kept thoroughly mixed in the above proportions in an air-tight bottle and when needed 1 heaping tablespoonful should be mixed with a cupful of water. This is one adult dose and should be repeated.

"Should there be no tannic acid on hand, a cupful of very strong tea or tea of oak bark will take the place of the tannic acid and water.

"Vomiting or puking may be induced by tickling the throat with a feather or pushing the finger down the throat, or by the administration of one of the following emetics by mouth:

"*Mustard.*—One tablespoonful stirred to a cream with a cupful of tepid water.

"*Common Salt.*—One tablespoonful to a cupful of tepid water. Not very certain as an emetic.

"*Alum.*—Two teaspoonfuls to a cupful of tepid water. This is a rather feeble emetic.

"*Ipecac.*—Give 1 tablespoonful of the sirup in a cupful of tepid water. Repeat once if necessary.

"The doses recommended throughout this article are for adults; the amount should be proportionately small for children as follows. Divide age of child by 12 more than age. For 6 year old $\frac{6}{6 + 12} = \frac{6}{18} = \frac{1}{3}$ of adult dose.

Unknown Poison

"Give 'general antidote' following by emetics or raw whites of several eggs; or, in their absence, milk, or flour and water. The white of egg, particularly, is inclined to pick up part of the poison left in the stomach and hold it until the patient can be made to vomit again. If the body is limp and respiration is feeble, tea or coffee can be given as a stimulant, and warmth applied to the body with massage or rubbing will tend to support the circulation.

Opium, Laudanum, Paregoric, Morphine, Codeine, Heroin, Indian Hemp

"Give the 'general antidote,' or potassium permanganate (1/3 teaspoonful dissolved in a pint of water, no undissolved crystals should remain in the fluid), or peroxide of hydrogen (2 teaspoonfuls in a pint of water), or borax, or baking soda (about 1 tablespoonful to the pint of water) followed by an emetic. Whites of eggs and considerable quantities of strong tea or strong black coffee should be given, or if unable to swallow, inject the coffee into the bowel with a syringe.

"Give sweet spirits of niter (1 teaspoonful in water three times a day) to aid excretion by kidneys.

"Keep patient awake by shaking, striking with wet towel, applying cold water over face and chest, or forced walking.

"Wines and liquors must not be given.

"When respiration becomes slow and irregular, artificial respiration should be employed, the same as is used to restore the partially drowned.

"After the dangerous symptoms have subsided, the patient should be put in bed, warmth applied, and he should be carefully watched for some time.

Arsenic, Ratsbane, Paris Green, "Rough on Rats," Fowler's Solution

"The best antidote, if the ingredients can be obtained, is prepared by mixing a teaspoonful of magnesia with a cup of water, adding 2 tablespoonfuls of tincture of iron, stirring well, and giving the whole in one dose; or the 'general antidote' may be given, followed by emetics, raw whites of eggs mixed with water, or large drinks of hot greasy water, or salt and water (tablespoonful to pint), or strong tea. Magnesia may be given in tablespoonful doses mixed with water. Lime water in large quantities is of some value, and in its absence lime which may be scraped from the walls or ceiling and mixed with water may be administered.

"Protect stomach with 2 tablespoonfuls of sweet oil, gruel, starch, mucilage, flaxseed tea, or elm-bark tea. Castor oil (2 tablespoonfuls) should be given after vomiting occurs even though the bowel movements are frequent.

"Pain can possibly be lessened by hot bottles to the stomach and bowels.

"Keep patient warm with artificial heat or extra garments, and give strong coffee to avert collapse.

Strychnine, Nux Vomica (Dog Button), Fish Berries, Ignatia Bean

"Give 'general antidote' or charcoal (1 tablespoonful) or strong tea followed by an emetic, then 15-gr. doses of bromide of soda or potash in water repeated every hour until three or four doses have been taken. Several whiffs of ether may be inhaled from a handkerchief at the beginning of a spasm.

"Give sweet spirits of niter (1 teaspoonful in water three times a day).

"Follow by a purge of Epsom salt or any other saline cathartic that is at hand.

"Artificial respiration should be employed the same as is used to restore the partially drowned (p. 1713). Remove the patient to a darkened room and keep as quiet as possible; avoid any sudden noises.

Bichloride of Mercury (Corrosive Sublimate)

"Promote vomiting, if not already present, by giving mustard in water. Do not use salt as an emetic.

"Give raw whites of eggs in water or milk or give milk or mucilage in abundance. In absence of eggs, chop up raw, lean meat finely and diffuse through water or milk and give. It is necessary that vomiting be induced after the eggs, milk, or meat are given, as the mixture formed of these substances will be absorbed if allowed to remain.

"The 'general antidote,' strong tea, and later flour and water, barley water, or flaxseed tea, or elm-bark tea may be given.

"Borax in water, about a tablespoonful to the pint of water, is recommended, but is of doubtful value.

"Stimulate with strong coffee if necessary.

Acid Poison—Acetic, Muriatic, Nitric, Sulphuric, Etc.

"Give no emetic.

"Give 'general antidote,' large drinks of water (or milk) with chalk, whiting, borax, magnesia, or baking soda, or wood ashes, or strong soapsuds; plaster from the wall may be given in emergency; olive oil, raw whites of eggs beaten up with water, and later flaxseed tea, elm-bark tea, gruel, starch, mucilage freely.

"Laudanum (20 drops) may be given if there is much pain.

Carbolic Acid and Cresol and Coal-tar Disinfectants Generally

"Give alcoholic liquors (whisky, brandy, etc.) or equal parts of alcohol and water freely to dissolve the poison. Produce vomiting to get rid of the alcoholic mixture. In the absence of alcoholic liquors, give vinegar, soapsuds, or raw whites of eggs in water. Give solution of Epsom or Glauber salt or sodium phosphate well diluted to hasten elimination of acid that may have entered the circulation.

"Do not give oils or glycerin.

"Milk, gruel, flaxseed tea, or elm-bark tea may then be given. Hot applications to extremities. For collapse give strong coffee. Apply artificial respiration if breathings tops.

Alkali Poisons—Lye, Hartshorn, Pearlash, Etc.

"Assist vomiting with large drinks of tepid water.

"Give vinegar, lemon juice or orange juice, hard cider, whites of eggs beaten with water.

"Follow by sweet oil, milk, gruel, barley water, flaxseed tea, or elm-bark tea.

Ptomaine Poisoning from Fish

"The symptoms of ptomaine poisoning are practically the same as those of cholera morbus.

"General antidote, emetics, copious drinks of strong tea, repeat emetic, then castor oil (2 tablespoonfuls) should be given. Continue treatment as given for cholera morbus.

Cholera Morbus (Sporadic Cholera)

"Cholera morbus is an affection of the stomach and intestines, attended by vomiting, purging, and cramps. It comes on suddenly, and may begin by vomiting or purging. It is usually met with during the hot months of summer. It is frequently caused by eating unripe and indigestible fruits and vegetables, decomposed or improperly cooked fish, shellfish, or salad mixtures. Drinking large quantities of iced water and sudden checking of the perspiration, or irritants of any kind, may set up the trouble. The disease usually begins suddenly, often at night, with vomiting, after a feeling of uneasiness, nausea, or a severe cramp. The contents of the stomach are first thrown up, then a bilious matter. The stools are at first solid or semisolid, but they soon become more watery, lose their color, and sometimes appear not unlike the rice-water stools of genuine Asiatic cholera. The patient soon has a wasted look. His thirst is unquenchable. His skin may become cold and clammy and the pulse very weak. Cramps may occur in the feet and in the calves of the legs. The disease runs a rapid course. The acute symptoms may subside in a few hours. The attack seldom lasts more than 12 hr. Recovery is the rule, but treatment should be promptly applied.

"**Treatment.**—Apply a large mustard plaster to the abdomen. Give 15 drops of laudanum. If the dose is rejected (immediately vomited), try it again. If it is still not retained, then try two tablets of Sun cholera mixture. If vomiting quickly occurs, then inject into the rectum by means of a glass or rubber syringe about 20 drops of laudanum mixed with a little thin starch or a little water. The rectal injection should be given immediately after an evacuation, and the patient should be instructed to hold it as long as possible. In whatever way the remedy is given, the dose should be repeated in about one hour if the vomiting and purging continue.

"If must not be forgotten, however, that all these remedies contain opium, and that if the patient is inclined to sleep or shows other constitutional effect of the drug the dose must not be repeated.

"The nausea and thirst may be controlled by cracked ice placed in the mouth. Small quantities of carbonated water may be allowed. If the thirst is very urgent a tablespoonful of iced water may be given at short intervals.

Poison Ivy

"**Treatment.**—Bathe with salt water or a boric acid solution, 1 teaspoonful in a glass of hot water. Open the large blisters and let the water out. Every day bathe the infected areas with warm water, dry without rubbing, and apply the boric acid solution.

Sunstroke

"**Cause.**—Prolonged exposure to strong rays of the sun or high humid temperature.

"**Prevention.**—Proper head and spine protection under tropical sun and avoidance of travel under extreme conditions of heat. Drink water sparingly. Oatmeal water in small quantities quenches thirst.

"There are two varieties of trouble:

"1. Heat stroke (heat fever), in which the body temperature is high.

"2. Heat prostration, in which the surface of the body is cool, sometimes below normal.

"*The difference is very important as the treatments are radically different.*

"**Symptoms and Treatment. Heat Stroke.**—Severe cases the victim may fall unconscious and die instantly. The usual case manifests intense headache, dizziness, nausea, vomiting and hot skin. Temperature may reach 105°F. Pulse full and may be either slow or rapid. Patient sinks into stupor and unconsciousness. They recover under treatment or die within 24 hr.

"*Treatment.*—Reduce temperature of body at once by cold-water bath. ice pack on head till temperature of body as shown by a thermometer in the rectum is reduced to 100°F. If the temperature rises again repeat the treatment.

"If the patient is exhausted after the reduction in temperature give $\frac{1}{40}$ gr. strychnine sulphate.

"**Heat prostration** with a cool skin and weak rapid pulse stimulants are required. Wrap patient in blankets, hot-water bottles at feet and around abdomen; give $\frac{1}{40}$ gr. strychnine sulphate. If head is hot, cold-water pack can be applied to head only. If vomiting occurs inject hot salt water solution into rectum (1 tablespoonful of salt to 1 pint of water)."

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Most used reference shown by **black face** type for page numbers.
The *italic* type for page numbers indicates that the reference is in the second volume where purchaser has the two volume edition. Volume I contains pages 1 to 746; Volume II, pages 747 to 1722.